

PAEE/ALE' 2025

**INNOVATIVE PATHWAYS:
BRIDGING PROFESSIONAL DEVELOPMENT AND ACTIVE LEARNING**

Porto, Portugal





TITLE

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22nd Active Learning in Engineering Education Workshop (ALE)
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Editors

Diana Mesquita, Valquíria Villas-Boas, Rui M. Lima

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ISSN

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<http://pae.dps.uminho.pt/>

This is a digital edition.

WELCOME TO PAEE/ALE'2025

Innovative Pathways: Bridging Professional Development and Active Learning

It is with great pleasure that we welcome you to the International Conference on Active Learning in Engineering Education, held under the theme “Innovative Pathways: Bridging Professional Development and Active Learning.” This conference brings together a vibrant and diverse community of educators, researchers, and students from around the world (Brazil, China, Colombia, Denmark, Ireland, Japan, Mexico, USA, and Portugal), united by a shared commitment to transforming engineering education through innovation, active learning, and project approaches.

The program of this edition has been carefully designed to meet three purposes:

- 1. Highlighting the professional development as an approach to foster teachers’ competences in implementing active learning and project approaches.**

As the demands on higher education continue to evolve in response to global challenges and technological transformation, the ability of teachers to adapt, innovate, and lead pedagogical change becomes paramount. Active learning is not simply a set of techniques - it is a mindset that requires educators to be reflective, collaborative, and committed to continuous learning. By foregrounding professional development in our discussions, we seek to empower participants to become agents of change within their institutions and beyond

- 2. Celebrating the ten-year collaboration between PAEE – Project Approaches in Engineering Education and ALE – Active Learning in Engineering Education.**

Over the past decade, this partnership has established a dynamic and growing platform that bridges research, practice, and community in the field of engineering education. The synergy between these two networks has enabled the sharing of diverse perspectives and fostered a shared vision that values student-centered learning, interdisciplinary exchange, and innovation in educational design.

- 3. Maintaining a sense of community among participants, particularly for newcomers, by fostering opportunities for meaningful dialogue and knowledge exchange across disciplines.**

This conference serves not only as an academic gathering but as a space for meaningful dialogue, mutual support, and knowledge exchange across disciplines and cultures. In a world where collaboration is more vital than ever, we hope to foster connections that extend beyond the event itself, supporting a lasting network of educators, researchers, and students who are passionate about transforming teaching and learning.

As we embark on this shared journey over the coming days, we invite you to engage deeply, question boldly, connect openly, and, above all, to have fun. Let this conference be not only a space for learning but also a catalyst for new collaborations, renewed purpose, and inspired action.

To all of you, welcome to a community where learning is active, development is continuous, and the future of education is shaped together.

Diana Mesquita, Rui M. Lima & Valquíria Villas-Boas

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PAEE/ALE'2025 Invited Speakers

PAEE/ALE'2025 attracted renowned keynote speakers to share their knowledge and experience on professional development and active learning in higher education, especially in engineering education in this new era. We are honoured to have the following inspiring keynote speakers:

Xiangyun Du

Professor and Director at the UNESCO Centre for Problem and Project-Based Learning at Aalborg University, Denmark. Her research focuses on educational transformation through Problem-Based and Project-Based Learning methodologies in diverse social, cultural, and educational contexts. Prof. Du has extensive experience across engineering, STEM, teacher education, business, language teaching, and health education. She specializes in intercultural perspectives, curriculum and pedagogical development, faculty/staff development, and gender studies. She has worked extensively with educators across more than 30 countries, fostering significant pedagogical innovation. Recently, Prof. Du has supported the establishment of teaching and learning centres in multiple institutions. She has also led initiatives of educational change programs using complexity theory and systems-thinking approaches to support institutional transformation and empower educators as effective agents of change. She has authored over 280 publications, including monographs, journal articles, edited volumes, book chapters, and conference papers. Prof. Du is actively involved in editorial roles, including as Associate Editor for the European Journal of Engineering Education.

CLIL | Católica Learning Innovation Lab

Founded in 2021 at Universidade Católica Portuguesa (Portugal), is an interdisciplinary centre dedicated to advancing pedagogical innovation in Higher Education. Informed by design-based research and by the principles of the Scholarship of Teaching and Learning (SoTL), CLIL provides a collaborative platform for exploring, testing, and refining innovative teaching and learning practices. It promotes faculty development by empowering educators to lead the transformation of educational models. The lab fosters collaborative engagement across academic disciplines, supporting faculty in the co-creation and implementation of transformative pedagogical approaches. Through a wide range of faculty development initiatives, CLIL empowers faculty to design flexible, student-centred learning environments that promote lifelong learning and drive meaningful and sustainable change in teaching and learning.

Jamie Gurganus

Assistant Teaching Professor in the Engineering and Computing Education Program and the Associate Director of STEMEd Research in the College of Engineering and Information Technology at UMBC. She also serves as the Director for the Center for the Integration of Research, Teaching and Learning (CIRTL) in the Graduate School and is a Faculty Fellow for the Alex. Brown Center for Entrepreneurship. Her work focuses on the development of engineers, educators, and communities from P–12 through post-graduate levels, with expertise in engineering identity, global and entrepreneurial competencies, failure culture, first-year experiences, and capstone design. She is committed to innovative teaching practices, including gamification and hands-on, authentic learning and collaborates globally on STEM education initiatives. Dr. Gurganus serves on the national leadership board for CIRTL, is Program Chair and Co-Chair for the American Society for Engineering Education, and serves on several UMBC boards—including the Council for Global Engagement.

Her leadership and mentorship have been recognized with numerous honors, including a Presidential Award from the International Federation for Engineering Education Societies and an Erasmus Plus award in collaboration with Portugal. A prolific contributor to the field, she has developed curricula, published scholarly works in national and international spaces, and co-founded Advancing Engineering Excellence in P–12 Engineering Education—an initiative that led to the creation of the P12 Engineering Learning Framework. Dr. Gurganus also serves on the Editorial Board for the Journal for Educational Research Methods with Tsinghua University in China, and her dynamic teaching portfolio ranges from first-year courses to senior and multidisciplinary capstone experiences, including a multidisciplinary COIL course in Global Engineering course involving partners in Brazil, Portugal, and Germany.

PAEE/ALE'2025 Programme

An overview of the program is shown below. The event takes place at the Universidade Católica Portuguesa in Porto, Portugal.

	25/06/2025 - Wednesday	26/06/2025 - Thursday	27/06/2025 - Friday
08h30 - 09h00	Check In		
09h00 - 09h30	Welcome Ceremony	Check In	Check In
09h30 - 11h00	Keynote Speaker - Xiangyun Du Aalborg University (Denmark)	Interactive Session - CLIL Team Católica Learning Innovation Lab	Keynote Speaker - Jamie Gurganus University of Maryland, Baltimore
11h00 - 11h30	Coffee-Break	Coffee-Break	Coffee-Break
11h30 - 13h00	Paper Sessions	Paper Sessions / Student Session	Panel "Innovative Pathways" with L&T
13h00 - 14h30	Lunch	Lunch	Closing
14h30 - 16h00	Workshops	Workshops	
16h00 - 16h30	Coffee-Break	Coffee-Break	
16h30 - 18h00	Paper Sessions	Paper Sessions	
18h00 - 19h00	PAEE/ALE 2025 - Challenge & Sunset		
20h00		Dinner - WOW	

PAEE/ALE'2025 Detailed Programme

25 June 2025

9:00 - 9:00: Opening ceremony - Corticeira Amorim Auditorium

Isabel Braga da Cruz (Pro-Rector at Universidade Católica Portuguesa)

Raquel Matos (Dean of the Faculty of Education and Psychology, UCP)

Miguel Romá (Chair of the Active Learning in Engineering Education Network - ALE)

Rui Lima (Chair of the Project Approaches in Engineering Education - PAEE)

Diana Mesquita (Chair of the Local Organizing Committee PAEE/ALE'2025)

9:30 - 11:00: Keynote session – Corticeira Amorim Auditorium

Xiangyun Du - Aalborg University, Denmark



Do good intentions to pedagogical change lead to actual improvement of student learning? How to connect these through meaningful teacher learning

11:30 - 13:00: Paper Sessions 1, 2, 3

Chair: Anabela Alves			
	#	Authors	Title
Paper Session 1 Corticeira Amorim Auditorium	PAEE25-10007	Diogo Neto, Paulo Flores	Introducing a project-based learning approach in a course on design of machine elements: A case study in two public universities in Portugal
	PAEE25-86308	Hiroshi Hasegawa, Kayoko H. Murakami, Manabu Ichikawa, Kazunori Mano, Atsuko K. Yamazaki	Industry-Community-University-Finance Collaboration scheme for Project Based-Learning of Engineering Education
	PAEE25-21304	Marcelo Carneiro Gonçalves, Maria Gabriela Mendonça Peixoto, Gustavo Alves de Melo, Eugenia Cornils Monteiro da Silva, Simone Borges Simão Monteiro	Applying Project-Based Learning (PBL) to Enhance Engineering Education: A Case Study on Production System Design at the University of Brasília
	PAEE25-89970	Leonidas Sandoval Junior, Fabio Orfali	Identifying Key Course Units in Engineering Programs Through Grade Correlation Analysis
	PAEE25-47647	Anabela Carvalho Alves, Senhorinha Teixeira, Cristina Rodrigues, Carina Pimentel, Pedro Domingues, Susana Costa, Teresa Monteiro, Celina P. Leão	Tutoring and mentoring Industrial Engineering and Management freshman-students in Project-Based Learning

Chair: Diana Soares			
	#	Authors	Title
Paper Session 2 EC011	PAEE25-89416	Valquiria Villas Boas, Elisa Boff, Laurete Zanol Sauer, Dianne Magalhães Viana, Liane Ludwig Loder	Faculty Development for Engineering Professors: A Course Integrating Active Learning and Digital Technologies
	PAEE25-29251	Maitê Gil, Rita Tavares Sousa	Across the continuums: Faculty Perceptions of a Professional Development Programme in Higher Education
	PAEE25-35232	Ronara Reis, Diana Mesquita	Institutional Support for Active Learning: a case study in Portugal and Brazil
	PAEE25-14849	Andromeda Menezes Campos, Talita Molina Lopes Tanes	Teacher Training in Hybrid Learning Environments: Artificial Intelligence, Ethics and Socioemotional Aspects in the Digital Material Production Course
	PAEE25-84768	Sandra Fernandes, Alexandra M. Araújo, Elizabeth Real	Pedagogical Innovation for Student Success in Higher Education: Evaluating Impact of Faculty Training UPT

Chair: Shannon Chance			
#		Authors	Title
Paper Session 3 EC013		Shannon Chance , Mike Murphy, Celina P. Leão, Mircea Tobosaru, Mary Nolan	Engineering Ethics Education Bingo 1.0
	PAEE25-13831	Lilian Barros Pereira Campos , Dair José de Oliveira, Marli Cristina Ferreira, João Paulo Romanelli, Rosa Silva, Hugo Almeida, Luiz Cordeiro Rocha	Robomat Project: attracting young students to STEM areas
	PAEE25-26388	Marien Rocio Barrera Gómez , Liliana Fernández Samacá	Bridging Innovation and Sustainability in Engineering Education: work in progress
	PAEE25-18766	Rafaela Villalpando Hernandez , Rene Diaz, Cesar Vargas-Rosales	Developing Scientific Female Leaders in STEM: the Road Trip of Female Mechatronics Students

14:30 - 16:00: Workshops 1, 2, 3

Workshop 1 - Dinis Carvalho What Really Drives Students to Learn? A Lean Coffee Discussion	EC011
Workshop 2 - Shannon Chance, Inês Direito Securing International Fellowships for Engineering Education Research	EC013
Workshop 3 - Valquiria Villas-Boas Unlocking Potential: Strategies for Motivating and Engaging Shy, Quiet Students in Engineering Education	EC019

16:30 - 18:00: Paper Sessions 4, 5, 6, 7

Chair: Rita T Sousa			
#		Authors	Title
Paper Session 4 Corticeira Amorim Auditorium	PAEE25-32656	Raquel Faria , Teresa Melo Fragoso, Nuno Cid Martins	Transforming Education: The Impact of Active Learning in Engineering Courses
	PAEE25-13875	Liliane Fonseca , Sergio Campello, Andrea Ribeiro	Collaborative and Integrated Planning for the Institutional Introduction of Active Methodologies in Engineering Education
	PAEE25-19145	Jan Van Maele , Diana Bairaktarova, Veerle Bloemen, Inês Direito	Engaging more widely in design projects for engineering students. Student reflections on their experience and the perceived impact of empathic imagination tasks.
	PAEE25-29978	Maria Paula Oliveira , Ana Paula Nolasco, Paolo Vettori	Enhancing Student Engagement and Assessment
	PAEE25-31729	Inês Monteiro , Francisca Miranda, Diana Soares	Enhancing inclusive education in higher education: best practices for UDL implementation

Chair: Lilian Barros Campos			
#		Authors	Title
Paper Session 5 EC011	PAEE25-63825	Andromeda Menezes Campos , Lilian Barros Pereira Campos , Dianne Magalhães Viana , Valquíria Villas-Boas , Carlos Eduardo Santi, Maria Duarte Freitas	Adoption Journey of Active Learning Strategies: reflections from Brazilian perspective
	PAEE25-72380	Lucio Garcia Veraldo Junior, Cristiano Jesus	World Café Dynamic: active learning to address Quality Tools
	PAEE25-24512	Lilian Barros Pereira Campos , Claudia Akemi Izeki, Vitor Guilherme Carneiro Figueiredo, Walter Aoiama Nagai, Leonardo Evangelista, Adriel Cunha	Project based curriculum: multi-case analysis from Brazilian public universities
	PAEE25-24916	Francisca Miranda , Inês Monteiro, Diana Soares	Pedagogical Relationship and Teaching Strategies in Higher Education: The Students' Perspective
	PAEE25-44810	Tom O'Mahony , Sinead Huskisson	Actively Teaching the Teachers: Impact of a Professional Development Initiative for Early Career Staff in Higher Education

Chair: Jens Myrup Pedersen			
#		Authors	Title
Paper Session 6 EC013	PAEE25-18434	Maria Teresa Monteiro	Formative assessment by biomedical engineering students to enhance the learning process
	PAEE25-36326	André Uébe-Mansur, Anabela Alves	Student Assessment under Complex Thinking: Driving gamified self-made Students' summative assessment
	PAEE25-10060	Jens Myrup Pedersen , Kristian Helmer Kjær Larsen, Mikael Vingaard, Jens A. Nielsen, Emil Nielsen, Hans Ravnkjær Larsen	Best Practices and Guidelines for Cyber Security Training
	PAEE25-16997	Olga Bernaldo , Maria Cruz Gaya, Pedro Lara, Alberto Sols	Bridging Industry and Academia through Project Based Learning
	PAEE25-16590	Gerardo Salvador González Lara , María Eugenia Morales Hinojosa, Manuel Cebal Loureda	Human flourishing versus burnout syndrome in the university environment: The case of Club 1943 - Karaoke del Tec de Monterrey
	PAEE25-22557	Luciano Pereira Soares, Rafael Corsi Ferrão	Enhancing Capstone Project Workflow: A Management Platform Case Study

Chair: Miguel Romá			
#		Authors	Title
Paper Session 7 EC019	PAEE25-12172	Miguel Romá Romero , Josep David Ballester Bermán, José Antonio Signes Gómez, Tomás Martínez Marín, Juan Manuel López Sánchez, Víctor Cazcarra Bes	Using GEN-AI to support learning in an engineering PBL environment
	PAEE25-24108	Andres Leonardo Alfonso Diaz, Marien Rocio Barrera Gómez , Liliana Fernández Samacá	Immersive Technologies for Engineering Education: A Virtual Reality Experience at the UPTC Geology Museum
	PAEE25-29228	Tiago Brandao Costa , Esoly Madeleine Bento dos Santos, Denise Hirayama	Artificial Intelligence in Engineering Learning: How Do Engineering Students Use it?
	PAEE25-55418	Andreia Magalhães , António Andrade	Teaching and learning with Artificial Intelligence
	PAEE25-55661	Eugenia Cornils Monteiro da Silva, Antônio Augusto Maciel Guimarães, Marcelo Carneiro Gonçalves , Marcelo Becker, Sanderson Cesar Macedo Barbalho	Immersive Classroom with Augmented Reality: Cognitive Evaluation and Perceptions of Production Engineering Students in Assembly Assistance

18:00 - 19:00: PAEE/ALE 2025 - Group Photo Challenge & Sunset

26 June 2025

9:30 - 11:00: Keynote session – Corticeira Amorim Auditorium
Católica Learning Innovation Lab – UCP, Portugal



Behind the Scenes: Inside Faculty Professional Development Centre for Active Learning in Higher Education

11:30 - 13:00: Student Session 1,2 & Workshop 4

Workshop 4 - Montse Farreras	EC019
Learning programming with Generative AI: Hands-On Exploration and Ethical Reflection	

Chair: Francisca Miranda			
	#	Authors	Title
Student Session 1 Corticeira Amorim Auditorium	PAEE25-23624	Thaís Luíza R. de Sousas, Michele C. Martins, Marcelo A.K. Filhos, Simone B. S. Monteiro, Rodrigo P. Gomes, Iara Gomes Andrade	Enhancing Digital Learning Accessibility: Usability Testing of the Educado Platform for Waste Pickers' Training
	PAEE25-23906	Iara Gomes Andrade , Luíza Andrade Cavalcanti, Giovanna Longo Rocha, Camila Valença, Simone Borges Simão Monteiro, Rodrigo Gomes	International Collaboration in Enhancing Educado: Prioritizing Requirements for an Educational Platform Supporting Waste Pickers in Brasília
	PAEE25-24271	Pedro Gonçalves Prazeres, Yasmim Bezerra Oliveira Altoé, Davi Cunha Vanderlei, Simone Borges Simão Monteiro, Iara Gomes Andrade	EcoLink: A Digital Platform for Sustainability, Community Engagement, and Waste Management
	PAEE25-12920	Beatriz Brito Silva, Inês Brito Silva, Maria Pereira, Maria Inês Torres, Marta Fernandes Ribeiro , Raquel Oliveira, Sandra Mariana Costa, Anabela Carvalho Alves	Hands-On Activity in 3rd Year Industrial Engineering and Management: Students' Perspective
	PAEE25-27612	Eduardo Silva , Andreia Bargas, Igor Subtil, Teresa Leite, Ana Felgueiras, Bárbara Oliveira, Francisca Abreu, Inês Ferreira, Maria Ferreira, José Dinis Carvalho	Analysis of the production system of a corrugated board company
	PAEE25-73871	Laura Camila Grimaldos Velandia , Liliana Fernández Samacá	A PBL Approach Design for Fostering Female Vocations in IT Engineering

Chair: Inês Monteiro			
	#	Authors	Title
Student Session 2 EC011	PAEE25-37564	Kelly Teixeira, Anne Karoline Oliveira , Laura Sousa, Simone Aparecida Lisniowski, Maura Milfont Shzu, Dianne Magalhães Viana, Andressa Coelho, Luísa Gabriela Frota	Engagement and Representation in STEM: Active Learning from the Perspective of Undergraduate Extension Students
	PAEE25-16844	Ana Carolina Cunha, Ana Catarina Abreu, Luísa Machado, Bárbara Silva, Carolina Pereira, Catarina Wilson, Inês Araújo, Lara Correia , Raquel Dantas, Rui M. Lima	From Classroom to the Industry: PBL in Action from the point of view of a team of students
	PAEE25-25688	Sebastian Cisneros Hernandez , Alberto Ordaz Cortes, Juan Silvestre Aranda Barradas, Carolina Ramírez Martínez	Strategies for Rapid Learning in SuperPro Designer through a Course on Biotechnological Process Planning
	PAEE25-44441	Daniel Arriaga-Ventura , Israel Ulises Cayetano-Jiménez, Rogelio Bustamante-Bello	AxoloBot: Design and Development of a Bioinspired Robot Based on a Modular Platform
	PAEE25-57450	Inês Brito Silva , Beatriz Brito Silva, Marta Fernandes Ribeiro, Violeta Carvalho, Cristina Rodrigues, Ângela Silva, Carina Pimentel, Rui M. Sousa, Senhorinha Teixeira	Which Transferable Skills do Students Acquire in PBL? Insights from the Industrial Engineering and Management Course

14:30 - 16:00: Workshops 5, 6, 7

Workshop 5 - Erik Lopes How to Develop a Chatbot in Less Than 90 Minutes: Hands-On Workshop on Emerging Technologies for Active Learning	EC011
Workshop 6 - Miguel Romá Inclusion of ethics in engineering education: "Ethics pills"	EC013
Workshop 7 - Shannon Chance, Inês Direito Supercharging Your Classes with RIHEEE Ethics!	EC019

16:30 - 18:00: Student Session 3 & Paper Sessions 8, 9, 10

Chair: Francisca Miranda / Inês Monteiro			
	#	Authors	Title
Student Session 3 Corticeira Amorim Auditorium	PAEE25-65021	Sofia Moreira , António Dinis Marques	The Role of Project-Based Learning in Developing Sustainable Fashion Solutions: Insights from the Eco-Design Challenge
	PAEE25-26328	Erik Teixeira Lopes , Yasmim Bezerra Altoé, Pedro Prazeres, Luiza Araujo, Simone Borges Monteiro, Diana Mesquita, Rui M. Lima, Jens Myrup Pedersen	Using a Chatbot for Student Onboarding and Learning in Projects: Technology as an Enabler of Active Learning
	PAEE25-29657	José P. Martins , Davide Rodrigues, Ana M. Pereira, Beatriz Silva, Diana Lima, Gonçalo Mendes, Maria B. Gomes, Ana R. Calvão, Rui M. Sousa	Project-Based Learning in cooperation with Industry: a case study in a textile company
	PAEE25-39360	Jose Cristiano Pereira , Francisco Carlos Meira, Alexandre Sheremetieff, Fabini Hoelz, Flavio Frade, Fabio Esperança	Use of AI (Artificial Intelligence) in the Risk Response Actions in the Preparation of Undergraduate Final Project Reports Using Project-Based Learning
	PAEE25-73466	Andressa Cristina da Silva, Cezer Souza Filho, Isabela Ferreira, Luciano Moura, Pedro Langendorf Vieira, Simone Borges Monteiro, Iara Gomes Andrade	Development of a Visual Tool for Carbon Footprint Assessment within an International Collaboration for Sustainability Monitoring

Chair: Rui M. Sousa			
	#	Authors	Title
Paper Session 8 EC011	PAEE25-69788	Cristiano Jesus , Lucio Garcia Veraldo Junior, Francisco Claro, Paulo César Anacleto Filho, Ivan Amorim, Sérgio Ivan Lopes	Integrating DevOps and Problem-Based Learning: A Teaching-Learning Experience in Project Management with Foundations in Scientific Materialism in the Network and Computer Systems Engineering Course
	PAEE25-78073	Roger Júnior Campos, Lílian Barros Pereira Campos , Janaina Antonino Pinto, Tatiana Gesteira de Almeida Ferraz, Camila de Sousa Pereira	Enhancing transversal competencies through PBL: insights from peer and self-assessment
	PAEE25-79142	Jose Amorocho Rojas, Martín Rogelio Bello, Claudia Fernanda Romero Flores, Javier Alberto De la Tejera De la Peña, Daniel Alberto Arriaga	From theory to practice: A motion capture project (methodology) as a platform for active and problem-based learning.
	PAEE25-81875	Julio Urbano, José Ramírez , Esteban Rosero	Experience Integrating an Interdisciplinary Schema of Project Based Learning on an Engineering Program
	PAEE25-83259	Lukas Souza, Rodrigo Silva Fregonasse, Natália Ilha Gattai, Pedro Affonso Faria, Simone Borges Monteiro, Yasmim Bezerra Altoé, Dianne Magalhães Viana	Development of a Visual Tool for Data Management in Recycling Cooperatives: A User-Centered Approach

Chair: Sandra Fernandes			
	#	Authors	Title
Paper Session 9 EC013	PAEE25-33091	Crediné Silva de Menezes, Rosane Aragon, Andromeda Menezes Campos , Alberto Nogueira de Castro Junior	Enhancing Pedagogical Architectures through the use of ChatGPT
	PAEE25-49078	Montse Farreras	Experiences and recollections with Generative AI in Introductory Programming: A Case Study
	PAEE25-71249	Sandra Fernandes , Alexandra M. Araújo, Pedro Rodrigues, Sara Fernandes	Generative AI in Academic Assignments: Insights from University Students and Faculty
	PAEE25-76194	Eugenia Cornils Monteiro da Silva, Antônio Augusto Maciel Guimarães, Marcelo Carneiro Gonçalves , Marcelo Becker, Sanderson Cesar Macedo Barbalho	Teaching Machine Learning in Production Engineering: Developing Practical Applications for Professional Training

Chair: Andreia Magalhães			
	#	Authors	Title
Paper Session 10 EC019	PAEE25-53557	Gerardo Salvador González Lara , Arturo Rodríguez Rodríguez, Manuel Cebal Loureda	Human flourishing and social service in engineering students
	PAEE25-23052	João Mello da Silva , Márcia Longen Zindel, Antônio Augusto Maciel Guimarães, Maria Fernanda bastos Campani	Learning needs analysis of waste pickers, for the elaboration of instructional design of courses for the EDUCADO platform
	PAEE25-89591	João Mello da Silva , Márcia Longen Zindel, Simone Borges Monteiro, Antônio Guimarães, Maria Campani, Frej Slot Arnfred, Lutfor Rahman Rabbi, Hristiyan Bozhilov	Digital Mobilizer App: A Mobile Phone App to Introduce Basic Environmental Education and Motivate Population Engagement in Sustainable Development through Personas Created by Waste Pickers
	PAEE25-17826	Cherie Mai Caloyloy Hansen	Cultivating diversity in cyber security with non-technical Capture the Flag challenges
	PAEE25-23348	Teresa Sofia Amorim Lopes Faria , José Paulo Marques dos Santos	Transforming Marketing Education: How PBL and Flipped-Classroom Improve Learning Outcomes

20:00: Dinner
Wow Porto

27 June 2025

9:30 - 11:00: Keynote session – Corticeira Amorim Auditorium
Jamie Gurganus – University of Maryland, Baltimore County (USA)



Unlocking Teamwork: Empathy in Action

11:30 - 12:30: Panel "Innovative Pathways" with L&T Centres - Corticeira Amorim Auditorium

Sandra Fernandes (Portucalense University, Portugal) – chair
Xiangyun Du (Aalborg University, Denmark)
Jamie Gurganus (University of Maryland, Baltimore County, USA)
Sandra Soares (University of Aveiro, Portugal)

11:30 - 12:30: Closing Ceremony - Corticeira Amorim Auditorium

Winner Announcement of Student Award 2025
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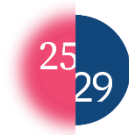
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PAEE/ALE'2025 Submissions

The PAEE/ALE'2025, International Conference on Active Learning in Engineering Education, joins the International Symposium on Project Approaches in Engineering Education – PAEE, which is being organized by PAEE association, the Department of Production and Systems, of the School of Engineering, University of Minho, since 2009, and the ALE workshop, which is being organized by the Active Learning in Engineering Education - ALE Network, since 2000. PAEE/ALE'2025 aims to join teachers, staff, managers, and researchers concerned with Engineering Education, to enhance engineering education using Active Learning and Project Approaches through workshops and discussion of current practice and research.

The event has three types of submissions in English:

- **Full Papers** for paper sessions, including standard research submissions, and papers of innovative experiences describing implementation issues. Students' submissions are published under this type of submission.
- **Hands-on and Workshop submissions**, aiming to encourage discussion of current practice and research on project approaches.
- **Abstract submissions**, which are short submissions that may be included in paper session presentations or poster session presentations.

The PAEE/ALE'2025 scientific committee double reviewed all full paper submissions, and in some cases had a third review. PAEE/ALE uses a single blind review procedure. After notification of acceptance, authors were invited to submit a final paper of 6 to 8 pages long in Microsoft Word format, using the available template. Accepted contributions were invited to make a presentation at the symposium.

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- Expect original submissions from the authors and discourage misconduct.
- Expect that authors are responsible for language quality.
- Expect that the authors adequately reference the sources of their work.
- Ensure confidentiality of submissions and reviews.
- Reviewers do a fair and detailed review of paper(s) assigned to them.

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PAEE/ALE'2025 Full Papers

Submissions accepted for the PAEE/ALE'2025 papers sessions.

Introducing a Project-Based Learning Approach in a Course on Design of Machine Elements: a Case Study in Two Public Universities in Portugal

Diogo Neto¹, Paulo Flores²

¹ CEMMPRE, ARISE, Department of Mechanical Engineering, University of Coimbra, Portugal

² CMEMS-UMinho, Department of Mechanical Engineering, University of Minho, Guimarães, Portugal

Email: diogo.neto@dem.uc.pt, pflores@dem.uminho.pt

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Abstract

This study explores the integration of the Race Party challenge, as a project-based learning approach, in the design of machine elements courses at the Universities of Coimbra and Minho. The Race Party challenge is a pedagogical activity, in which the students, organized in teams, are required to design, develop and construct a minicar to run five meters in a flat surface, as fast as possible. Besides the instructive approach associated with traditional design of machine elements course, the students also embrace the managerial dimension of the project organization. Assignments, deliverables, laboratory activities, written reports, oral presentations and the competition at the end of the semester provide students a good number of hands-on learning experience incorporating various didactic aspects in a structured manner. Within the scope and objectives of the Race Party project, students can not only apply knowledge from previous curricular units, but also acquire and develop soft skills, such as teamwork competences. The Race Party project demands students to creatively solve open-ended problems with a clear success metric and guided sequence. The Race Party is a simple, safety and practical activity, yet it is a highly demanding project, since involves different aspects associated with the design of machines elements. Thus, the main objective of this work is to present a pilot study carried out at the Universities of Coimbra and Minho, where the Race Party challenge was implemented in a course on machine design. For this purpose, the students' voice is the key instrument utilized to assess the effectiveness of this innovative pedagogical approach. By and large, it was recognized, by students and instructors from both universities involved, that the Race Party project is successful and effective for teaching and learning machine elements design.

Keywords: Project-Based Learning; Race Party Challenge; Engineering Education; Design of Machine Elements.

1 Introduction

Engineering education in the 21st century is undergoing a permanent and significant transformation to meet the evolving demands of industry and society. Engineers today face increasingly complex and interdisciplinary challenges, requiring a skill set that extends beyond traditional technical knowledge (Van den Beemt et al., 2020). According to the report "Engineer of 2020" by the National Academy of Engineering (Engineering, 2004), engineers must not only be sources of technical knowledge but also possess interdisciplinary problem-solving skills to integrate concepts from various scientific and technological fields. Therefore, in addition to technical expertise, engineers need soft skills, such as communication, leadership and teamwork. Thus, an innovative approach of engineering education is required to develop this interdisciplinary knowledge and skills (Litzinger et al., 2011). This is also the American Society of Mechanical Engineers 2030 vision (Kirkpatrick et al., 2011).

Since the quality of learning is largely dependent on teaching effectiveness, traditional lecture-based instruction, particularly in engineering, is no longer suitable to provide all the professional skills needed by contemporary graduates (Cheng et al., 2013). In response to this demand, universities across the world are under increasing pressure to update the engineering curricula, aiming to address the skills gap identified above (Mitchell et al., 2021). The need for a curriculum encompassing areas such as engineering's role within society and a whole set of transversal skills from critical thinking to team working have been strongly highlighted.

Moreover, adopting teaching and learning methodologies that activates student curiosity and hands-on work should improve motivation and reduce dropout rates (Terrón-López et al., 2017). Typically, these methodologies primarily resort to pedagogical strategies associated with active learning and project-oriented approaches (Hernández-de-Menéndez et al., 2019).

The shift from traditional lecture-based teaching to a student-centred-learning approach helps students to develop their professional skills and improve the adaptability required in the modern engineering workplaces. Adopting active learning approaches in engineering education allows students to engage directly in the learning experience, which improves the quality of learning in the short-term (Maceiras et al., 2025). Thus, active learning techniques such as project-based learning (PBL) (Gomez-del Rio & Rodriguez, 2022), flipped classrooms (Cho et al., 2021), collaborative group work, and hands-on laboratories (Gillet et al., 2005) are becoming increasingly prevalent in engineering education. These approaches not only enhance technical understanding but also foster the development of crucial transversal skills like teamwork, communication and problem-solving (McCrum, 2017).

The main objective of this work is to describe and discuss the implementation of a pedagogical project to promote the teaching-learning process of design and selection of machine elements among undergraduate students at the Universities of Coimbra and Minho. For this purpose, the Race Party Challenge was elected as a practical project, in which students, organised in teams, must design a minicar to race five meters on a horizontal and regular surface, as fast as possible. In order to make the design project more attractive and exciting for both students and instructors, the process of manufacturing and assembling of a physical prototype is also required. Within the scope and objectives of this pedagogical activity, the students will be able to develop technical skills in various areas, such as digital prototyping, mechanics, machine design, strength of materials, as well as manufacturing and assembling processes. In addition to these technical aspects, students can also develop soft skills such as teamwork, leadership and initiative, and the ability to communicate to a wide audience. The implementation of this design project embraces different pedagogical dimensions, such as lectures, laboratory activities, deliverables, written reports, oral presentations and written exams. This study discusses the impact of the proposed project-based learning approach as an effective manner to teaching machine elements in a non-traditional fashion.

The paper is organized in five main sections. Thus, after a brief introduction, Section 2 describes the Race Party competition, which is a project-based learning approach successfully applied at the Universities of Coimbra and Minho in the framework of the course Design of Machine Elements. Then, Section 3 presents the basic aspects related to the learning outcomes and assessment approaches in the spirit of the Race Party activity. In Section 4, some preliminary outcomes are presented and discussed, which allow to show a general picture of the implementation of the Race Party project at the Universities of Coimbra and Minho. Finally, in Section 5, the main concluding remarks are examined, and some potential future developments are discussed.

2 Race Party Pedagogical Activity

This section briefly describes the main features of the Race Party challenge, which was developed within the framework of a project-based learning approach. This specific pedagogical project aims to make the traditional machine design courses more applied and engaging for both students and instructors. As part of the Race Party challenge, students must develop a minicar that can travel five metres on a flat surface in the shortest possible time. For this purpose, each student team is provided with a basic kit at the beginning of the semester, which includes a piece of wood, a metal shaft, a plastic piece to support the shaft, two shaft holders and a

helical spring. Figure 1a shows the basic kit provided to the students, which must be considered during the design and construction of the minicar.

The main objective of the Race Party challenge is to design and build a dragster-type minicar, powered by a tensioned helical spring. Figure 1b shows an example of the minicar designed by a student team. The performance and success of the race will be judged on aesthetics, speed and reliability. The racetrack is shown in Figure 1c, with the start and finish lines separated by five meters. The educational activity of the Race Party includes lectures in traditional classroom presentations to discuss specific topics, such as dimensional metrology, safety rules in laboratories, dynamics of mechanical systems, design of machine elements, materials and selection of mechanical components, just to name a few. Students are expected to come prepared for lectures by reviewing the relevant course materials, including slides, textbooks, and YouTube videos. It should be noted that students spend a considerable amount of time developing and designing their solutions, as well as familiarizing themselves with the laboratories and machine shop.

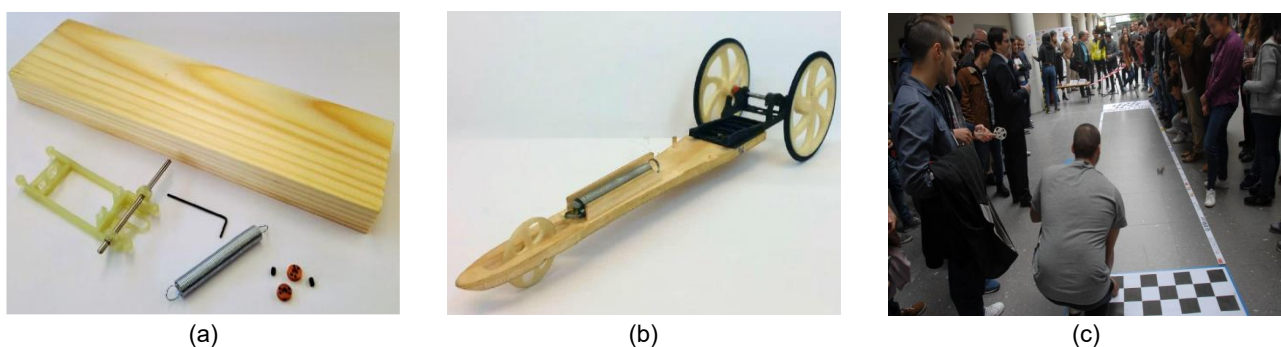


Figure 1. Race Party challenge: (a) basic kit provided to each student team; (b) example of a minicar developed; (c) racetrack used for the competition.

In the Race Party pedagogical activity, there are some key tasks and milestones to be carried out by the students, namely: (i) evaluate the spring stiffness using both analytical and experimental approaches; (ii) design and conceptualise the minicar solution, including the number of wheels, body aesthetics, and other factors; (iii) evaluate the dynamic performance of the minicar using a specific computational code developed for this purpose; (iv) develop a CAD/CAE/CAM model of the final minicar design for structural analysis and manufacturing; (v) select materials and mechanical components to build the physical prototype of the optimized solution for preliminary testing; (vi) exhibit the final version of the minicar during the Race Party competition.

Other important characteristics of the minicar developed as part of the Race Party project are: originality, simplicity, safety, portability, cost and adaptability to different conditions. However, all options and decisions made during this design project must be supported by engineering and scientific principles of mechanics. At the end of each task, each student team must submit a one-page report summarizing the key aspects and conclusions reached. In addition, each student team must give five oral presentations detailing the work carried out and the results obtained. The main purpose of using these tools is to encourage discussion with students about the process and product of the Race Party challenge. In particular, potential difficulties and conflicts within the teams can be identified and addressed in a timely manner.

Additionally, after the race, each team must create a short video summarizing the key aspects of the Race Party challenge. Students are informed of this requirement at the beginning of the semester and are encouraged to take photos and collect videos of all tasks and activities throughout the semester. Students are also required

to maintain and update their portfolio, which is regularly reviewed by both the tutor and the course coordinator. The main goal of using the portfolio approach is to actively engage students in the learning process related to the Race Party project, allowing them to track the progress of their individual and team contributions throughout the semester.

The activities and progress of the teams, as well as of each individual student, will be monitored through their attendance at the scheduled sessions. To facilitate this process, each student team is required to present their portfolio. Moreover, students are required to give mid-term and final oral presentations, produce mid-term and final reports, complete a series of deliverables and take three individual mini-exams. This wide range of aspects not only allows for continuous monitoring of the project's progress, but also facilitates the assessment and grading of both teams and individual students. It also exposes students to different learning techniques, which ultimately prove effective in achieving better results.

Success in this design project depends on teamwork. Students will be assigned to teams of five who will work together throughout the semester. It is expected that students within a team will work together on the design project, homework and other educational activities within the class. It is of paramount importance that teams deal with this in a positive and constructive manner. Teams that have problems working together should make every effort to resolve them themselves. Course instructors are always available to help and facilitate the smooth running of the team, but the ultimate responsibility lies with the team.

3 Learning Objectives and Assessment

The central idea of the Race Party challenge is to provide each student with a deep understanding of the dynamics and design of machine elements. Students will also acquire and develop technical skills in the selection of materials and mechanical components, mechanism design and manufacturing processes. In addition to these hard skills, students are also expected to acquire and develop soft skills such as teamwork, creativity, the ability to communicate with a wide audience and the ability to defend their views. In addition to the learning outcomes related to the Machine Elements courses, in which the Race Party challenge is included, there are specific learning outcomes directly related to this pedagogical project. Thus, at the end of the course, the students must be able to achieve, either individually or in team, at least the following objectives (i) identify the key variables related to the dynamics and performance of minicars; (ii) carry out basic kinematic and dynamic analysis of mechanical systems; (iii) design a machine for a specific purpose (performance, functionality, manufacturability); (iv) develop computational and physical models of machines and mechanisms for simulation, design and optimisation; (v) produce CAD models and technical drawings suitable for communication with the machine shop technician (vi) identify and select materials and mechanical components to build a machine; (vii) build, assemble and test a mechanical system using standard components.

Despite its simplicity, the Race Party project is a demanding pedagogical activity, encompassing multiple aspects related to mechanical system dynamics, design and selection of machine elements, as well as numerous assessment requirements. Notably, this project strongly adopts the assessment for learning approach, which not only motivates students but also enhances their learning process. Therefore, the assessment and grading of students in this project are based on the following components: (i) deliverables (maximum 1 page per submission); (ii) mini-exams (15 minutes each); (iii) final exam (30 minutes); (iv) mid-term oral presentation (30 minutes, including discussion); (v) final oral presentation (30 minutes, including discussion); (vi) mid-term report (maximum of 6 pages, excluding appendices); (vii) final report (maximum of 12 pages, excluding appendices). The weighting of each component may vary from year to year, based on the lecturers' experience and student feedback, which is collected and discussed during the first lecture of the semester.

Overall, the Race Party project is assessed on the merit of the students, which includes both the progress and the final product, as well as the quality of their reports and presentations. Furthermore, peer and self-assessment are encouraged throughout the semester, providing students with valuable feedback on their skills and comfort level in carrying out the various tasks associated with the project. In this pedagogical project, students are organized in teams, and each team is supervised by a tutor, who is faculty member. By organizing students into teams, they can acquire and develop teamwork skills. It should be emphasized that the tutors provide students with any clarifications and explanations needed throughout the semester, but they are not directly involved in the decisions made by the students. The activities and progress of the groups, as well as each individual student, are monitored through their attendance at the scheduled sessions.

During the semester, there are specific weeks, where students, in team, can reflect on the following questions: (i) "Within the Race Party project we have learned ..."; (ii) "We have difficulties in ..."; (iii) "We need help and support in ..."; (iv) "The team works well in ..."; (v) "The team can improve in ...". It should be noticed that, apparently simple, these questions reveal to be quite demanding and hard to be answered by students, since they are used to answering technical and direct questions. This has been an ongoing challenge for instructors in adjusting and improving the Race Party project over the years. In fact, this has been a tremendous challenge for instructors in terms of adjust and improve the Race Party project over the years. In addition, students are also asked to respond to a set of open questions such as: (i) "For me the most interesting aspects were ... because ...", (ii) "If I could give advice to future students of this course, I would tell them that ..."; (iii) "If I started this course today ...", (iv) "If I could give advice to future students of this course, I would tell them that ...".

4 Results and Discussion

This section deals with some preliminary findings that resulting from the implementation of the Race Party project at the University of Coimbra and the University of Minho, specifically within the Machine Elements course. Incorporating the Race Party activity into the syllabus was a demanding task, requiring substantial adjustments in the preparation and reorganization of the course. Originally, the course was structured around practical problems and exercises, following a learning-by-doing approach. The transition to a project-based learning methodology required careful planning and simplification of certain course elements in order to effectively integrate hands-on activities, while maintaining the core learning objectives. One of the key aspects was the establishment of milestones associated with the development of the project, allowing for student self-regulation as well as providing appropriate and timely feedback to the teams.

The Race Party project has demonstrated significant benefits to engineering education, particularly in improving students' understanding of dynamics of systems and design of machine elements. Throughout the course, students have successfully applied the theoretical knowledge to create an engineering solution (minicar) capable of fulfilling the required specifications, thereby strengthening their problem-solving and critical-thinking skills. The integration of computational and physical modelling has enabled students to refine their designs and optimise performance. Indeed, digital prototyping using CAD software and simulation techniques replaced the traditional trial-and-error approach, allowing students to quickly anticipate potential design problems, virtually test different configurations and resolve issues before building the physical prototype. This approach improved efficiency, reduced development time, and minimized costly errors.

The gradual improvement in students' ability to communicate effectively, both orally and in writing, is one of the key observations from this pedagogical project, as occurred in previous studies graduates (Cheng et al., 2013). The incremental assessment process, including reports and oral presentations, has significantly reinforced the importance of clear and structured communication in engineering. Moreover, the feedback from reports and presentations allows students to critically evaluate their own work and justify their decisions based

on technical evidence. This process promotes a deeper understanding of the subject as students are required not only to solve the engineering problem, but also to communicate their solutions to an audience that may not have the same technical background. In addition, students have developed visual communication skills, particularly through the use of CAD models and simulation results. These visual aids are powerful tools for explaining complex ideas, making their concepts more accessible and persuasive to a diverse audience.

The Race Party placed a strong emphasis on teamwork, recognizing that successful engineering outcomes are often the result of effective collaboration rather than individual effort. The need to coordinate and collaborate with team members helped students to develop key interpersonal skills such as active listening, negotiation and compromise. These skills are essential in engineering practice, where complex projects often require collaboration across different disciplines and expertise. Students learned how to manage differing opinions and ensure that all team members contributed their knowledge and ideas. Students were exposed to the importance of delegation and sharing responsibility. Effective teamwork involves understanding the strengths and weaknesses of each team member and assigning tasks accordingly. Through this project, students gained insight into how to optimise team performance by using the skills and talents of each team member.

The implementation of the Race Party within the Machine Elements course at both universities resulted in improved student academic performance, compared to traditional assessment methods based solely on a final exam. It was found that the final grade average was higher and the success rate was better compared to previous editions of the course without the Race Party project. Moreover, this engineering education project also contributed to a significant reduction in the number of students failing the course. Rather than focusing solely on a single high-stakes exam, students took a range of assessments, including reports, presentations and mini-exams, which encouraged regular study and active participation. As a result, students were better prepared and more confident in applying their knowledge, leading to improved performance and a more comprehensive understanding of the subject. The improved student's performance was also reported by (Hernández-de-Menéndez et al., 2019). The continuous nature of the learning process, combined with the practical application of concepts, proved to be more effective than relying on a final exam alone.

Student feedback, collected through anonymous surveys carried out at the end of semester, further reinforces the effectiveness of the Race Party project. Most students reported feeling more engaged and motivated compared to traditional lecture-based courses, which agrees with previous studies (Maceiras et al., 2025; Terrón-López et al., 2017). Another relevant outcome, which can be verified at both universities, relates to class attendance during the semester. Figure 2 shows students' perceptions of class attendance during the semester, comparing the two universities. As far as the University of Coimbra is concerned (Figure 2a), the percentage of students who attended at least 80% of classes increased from 45% to 58% after the application of the Race Party project. On the other hand, the percentage of students who attended less than 20% of classes decreased from 12% to 5%. The same result was obtained at the University of Minho (Figure 2b), where the percentage of students who attended 100% of classes increased, while the percentage of students who attended less than 50% of classes decreased. The survey results confirm that increased student attendance, together with their participation in the Race Party, was a key factor in the academic success of the Machine Elements course.

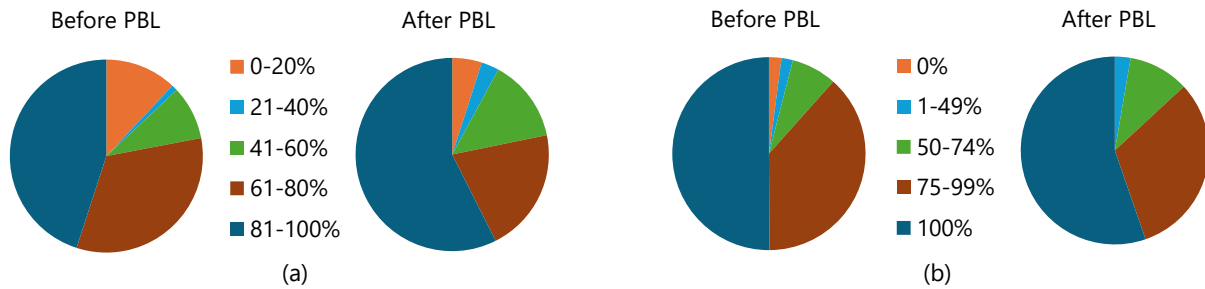


Figure 2. Perception of the students in relation to the attendance of classes during the semester: (a) University of Coimbra; (b) University of Minho

Student testimonials further highlight the positive impact of the Race Party on their learning experience:

- *"Excellent initiative by Professor [name omitted] for the car race initiative. I think that assembling and developing these cars made me realize and understand some of the concepts better in a more challenging and fun way"*, [anonymous response from a student, University of Coimbra]
- *"The idea of including a car race (Race Party) as a practical part was simply brilliant, this approach made learning much more dynamic and interesting"*, [anonymous response from a student, University of Coimbra]
- *"I believe that this evaluation system is really important for future students and that despite it also being challenging for the teacher, I think that it is a job that the students will always remember as a unique and fun job"* [anonymous response from a student, University of Coimbra]
- *"Overall, I was very satisfied with the learning I obtained in this subject and I would like to highlight the merit of the teacher [name omitted], for his initiative with the "Race Party" project and for the way he helped and motivated his students"*, [anonymous response from a student, University of Coimbra]
- *"Creating a project like "Race Party" encouraged students to want to learn even more and made the course even more interesting. The objective and clear way of teaching classes, both theoretical and practical, helped them understand the subject in the best possible way"* [anonymous response from a student, University of Coimbra]
- *"The Curricular Unit was the best I have ever had. Professor [name omitted] is the type of professor that I wish existed in all UCs. His interest in student learning, knowledge and concern for his UC was impeccable"* [anonymous response from a student, University of Minho]
- *"In general, the course is very interesting and rewarding, as it demonstrates the results of the effort made throughout the semester in a more perceptible way, at a practical level"* [anonymous response from a student, University of Minho]
- *"Personally, it was one of the courses that most interested me so far. This is due to its strong practical aspect, which has proven to be something rare"* [anonymous response from a student, University of Minho]
- *"Professor [name omitted] was able to motivate students in relation to the projects to be developed and showed that he was always available to clarify possible doubts"* [anonymous response from a student, University of Minho]
- *"More subjects like this"* [anonymous response from a student, University of Minho].

Finally, it is worth mentioning that, while the Race Party challenge left instructors thoroughly exhausted by the end of the semester, they also felt deeply fulfilled and motivated by the students' enthusiasm and success. Figure 3 shows photos of the group of students from the University of Coimbra and the University of Minho. In fact, the Race Party project transformed the learning environment, shifting the focus from a teacher-centred approach to a student-driven experience. This transformation requires flexibility from instructors to accommodate students' difficulties and adapt the subjects covered throughout the semester, ensuring a more personalized and effective learning experience.



(a)



(b)

Figure 3. Family pictures of students and instructors: (a) University of Coimbra; (b) University of Minho

5 Conclusions

The Race Party competition, a project-based learning approach, was implemented in the existing Machine Elements course at the Universities of Coimbra and Minho. The syllabus was adjusted to accommodate the Race Party project, in terms of teaching approach, learning objectives and assessment. By integrating hands-on design, prototyping, and competition, this pedagogical activity bridged the gap between theoretical knowledge and practical application, promoting deeper understanding and engagement among students. The project not only strengthened technical skills in machine design, dynamics and materials selection but also developed essential soft skills such as teamwork, communication and problem-solving. Key outcomes from the Race Party challenge included better academic performance, higher class attendance and reduced dropout rates, evidenced by student feedback and institutional data. The incremental assessment framework, combining reports, presentations and mini-exams, were more effective than traditional exam-based evaluation. Students praised the initiative, highlighting it as a standout experience in their education. For instructors, the Race Party was both demanding and rewarding, requiring adaptability to student needs while shifting the classroom dynamic toward student-centred learning. Despite the challenges, the success of the project highlights the value of active learning methods in preparing engineers for interdisciplinary, real-world challenges. Future iterations could explore scaling this educational model to other engineering subjects. The

Race Party is an example of how innovative PBL approaches can transform engineering education, align with industry needs and inspire the next generation of engineers.

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Best Practices and Guidelines for Cybersecurity Training

Jens Myrup Pedersen^{1,2}, Kristian Helmer Kjær Larsen², Mikael Vingaard³, Jens. A. Nielsen³, Emil Schmidh Nielsen⁴, Hans Ravnkjær Larsen⁵

¹ Aalborg University, Department of Electronic Systems, Copenhagen, Denmark

² Campfire Security ApS, Hillerød, Denmark

³ ICSRange ApS, Sønderborg, Denmark

⁴ SagaLabs ApS, Aarhus, Denmark

⁵ Dansk IT, Copenhagen, Denmark

Email: jens@es.aau.dk, kl@campfiresecurity.dk, miv@icsrange.com, jan@icsrange.com, em@sagalabs.dk, hrl@dit.dk.

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Abstract

Cybersecurity has never been more important than today. While increasing digitalization brings many advantages, it also comes with increased risks of cyberattacks: A growing attack surface contributes to a higher probability of attacks, and increasing dependence on digital systems and services contribute to higher consequences of attacks when they are successful. On top of this, the geopolitical situation has also led to an increased activity among many different threat actors, including cyber criminals, nation states and cyber activists. One of the main challenges to combat the cyber threat is the lack of skilled people: Not only are we missing around 4 mio. cybersecurity professionals on a global scale: We also have a huge challenge of ensuring that the general public, and in particular those working with IT, have a strong knowledge of cybersecurity. This need for training is also addressed in new regulations, such as the NIS2 Directive in the European Union. In this paper, we define 20 principles for good cybersecurity training, with a particular focus on technical training that goes beyond awareness. The principles are based on a combination of theoretical knowledge, practical experience, and extensive dialogues with stakeholders from both industry and academia through joint trainings and workshops. The paper explores topics such as active learning, combination of theory and practice through hands-on exercises, collaborative learning, gamification with clear missions, scaffolding and the use of hints and real-world context and experience. We believe that the paper can serve as an important reference for development of trainings, training platforms and courses in cybersecurity. We also believe the methodology with collaboration across companies and academia can contribute to increase the quality of trainings, and eventually contribute to closing the cybersecurity skills gap.

Keywords: Active Learning; Cybersecurity; Innovation.

1 Introduction

The cyber threat against our societies, including individuals, companies, and government organisations, is higher than ever before. There is not a single reason behind this, yet some of the drivers are increasing digitalization which leads to both larger attack surfaces (thus increasing the probability of attacks) and a higher dependability on our IT infrastructure (increasing the consequences of attacks) as well as geopolitical changes that has led to an increase in both cyber activism and cyber espionage. One could also speculate that the geopolitical changes during the last 5-10 years might have given cyber criminals new opportunities with less probability of being prosecuted. In a Danish context, the governmental agency Centre for Cybersecurity has assessed the threats of both cyber espionage and cybercrime against Denmark as very high, the threat of cyber activism against Denmark as high, and the threat of destructive cyber attacks against Denmark as medium (CFCS, 2024). The picture is similar in most other European countries, and also on a global scale the challenges of cybercrime keep growing with the losses increasing every year (IC3, 2025).

One of the biggest challenges is the lack of competences. On a global scale, the 2024 ISC2 Cybersecurity Workforce Study (ISC2, 2024) estimates a global gap of 4,762,963 persons, an increase of 19,1% compared to the year before. On top of this comes a need to upskill the many people working with IT and digitalization: They might not need to become cybersecurity professionals, but they need a high level of knowledge to build,

maintain and operate systems in a secure manner. New legislation such as the NIS2 directive from the European Union is expected to increase the need for cyber competences even more.

Cyber ranges and cybersecurity training platforms (Kjorveziroski et al., 2020; Darwish et al., 2020) is a popular basis for making cybersecurity training active and engaging (Russo et al., 2023). These platforms usually provide virtual environments, where the learners get hands-on experiences in a closed and secure environment, often combined with gamification (Mahmoud et al., 2024). The objective of this paper is two-fold: We would like to spark a discussion about good cybersecurity training that goes “beyond awareness”, and we would like the paper to serve as a source for everyone developing and implementing cybersecurity training. The paper is based on a joint project supported by NCC-DK, the Denmark Cybersecurity Coordination Centre (NCC-DK, 2025) (co-funded by the European Union), where three companies that all work with cybersecurity training based on different platforms have joined forces to develop joint best-practice guidelines and principles for cybersecurity training. Campfire Security ApS is a spin-out from Aalborg University and based on a further development of the Haaukins platform (Panum et al., 2019), which provides training based on challenges in a format known as Capture The Flag. SagaLabs ApS is developing scenario based training, and is a spinout from the Danish Association of Cyber Alumni, i.e. former cyber conscripts. The initial platform and the name was inspired by Erhvervsakademi Aarhus, a Danish educational institution. Finally, ICSRange ApS is developing training specifically focusing on industrial systems and OT (Operational Technology). While the trainings share many characteristics, i.e. the use of virtual environments, active learning and gamification, both the platforms and the context in which they are used differ. In addition to the companies, the non-profit association Dansk IT is also participating in the project. Dansk IT is a central player for IT professionals in Denmark and works to promote the role of IT in both society and business. As an independent interest organization, Dansk IT brings together members with a common desire to strengthen professionalism, drive digital development and ensure responsible use of technology. For this project in particular, the organisation includes a large share of the Danish cybersecurity community. This paper is motivated by the desire to learn from each other and from the theory in order to enable the educational and cybersecurity community to provide even better trainings.

2 Methodology

The 20 principles in this paper have been developed throughout 2024 and 2025, based on a number of sources and activities:

- Scientific literature, including that listed in Section 1 of this paper.
- Practical experience by the authors of this paper. The authors represent three different platforms as also described in Section 1, and therefore experiences with different learning needs, methods and target groups. In the context of this paper, 8 jointly arranged training events were held, where participants used one or more different platforms, and the authors observed the use and afterwards discussed and evaluated points to include as joint principles. After each training, an oral evaluation was done with the participants, who also provided inputs to the discussions and thus the principles. Most of the events were open so anybody could attend and attracted a variety of mainly IT professionals – both technical profiles such as developers/programmers and less technical profiles such as IT architects and managers. These events included the following examples, each making use of two different platforms:
 - On November 6, 2024, we did a 4-hour evening event with focus on security of Operational Technology. The first part of the event focused on learning techniques and practical tools, whereas the second part was scenario based: In a virtual environment, the participants were tasked with a mission of hindering an enemy fleet in leaving the harbours. The scenario was called “Operation Northern Shield”.

- On March 6, 2025, we did a full day event with hands-on introduction to cybersecurity, targeting all IT professionals. The morning part of the workshop was focusing on hands-on cybersecurity fundamentals in a Capture-The-Flag format, where the participants should solve challenges in virtual labs, and where each challenge would result in points. In the afternoon, the participants should apply the tools and techniques from the morning in a realistic scenario, "Operation Hidden Spice", in a threat-hunting mission, where the task is to confirm or refuse the suspicion that an employee may have acted as an insider.
- A total of 4 workshops were held, which were open to the public and mainly attended by people from the Danish cybersecurity community, with the aim of discussing the principles. They were usually attended by a smaller group of 5 externals, but included both people with technical and didactical backgrounds, and led to changes, adjustments, and additions of new principles. The workshops mainly focused on discussing two documents:
 - The Best Practices and Guidelines for cybersecurity training as outlined in this paper.
 - Ways of measuring and quantifying cybersecurity competences achieved during trainings, e.g. using the NICE framework (NICE, 2025) and the Dreyfuss model (Rousse & Dreyfus, 2021).

During the iterations of practical experiences and workshops, the number of principles grew from 10 to 20.

In the following, we will present the principles that we have agreed upon. The principles are structured so that each principle contains both motivations, descriptions and at least one example. The point of adding examples to all principles was actually a result of one of the workshops, since this increases the clarity and understanding even when the principles are applied by different target groups.

3 About the principles

When defining the principles, it is important to keep in mind that the overall goal of the principles is to provide common best practices and guidelines for cybersecurity training. It is established as part of a collaborative project within the cybersecurity training sector in Denmark and supported by NCC. The guidelines are not meant as a checklist to follow, but rather a set of best practices and guidelines to consider when designing cybersecurity training. Not all practices/guidelines are relevant for all aspects of cybersecurity training, and there can also be valid reasons for making different choices.

In our context, we are mainly covering cybersecurity training for IT professionals, including software and security professionals. We do not aim to cover e.g. standard awareness training for non-IT employees, but focus on trainings that provides the learners with skills and/or competences in addition to naturally raising awareness.

Finally, the principles are designed to be constantly developed based on continuously collecting inputs and experiences from relevant stakeholders.

4 The principles

This section presents the 20 principles.

In the descriptions, we sometimes refer to "challenges", which in this context means specific security-related puzzles or problems the learners must solve, and "flags", which in this context is usually a small text string that serves as a proof of completing a challenge.

4.1 Explain the purpose

To make sure the learners are motivated and see the value in the training, it is crucial to explain the purpose from the beginning: Why is this training important for them (and/or their company), what will they learn, and

how will it help them? For example, a person in the management role could learn about basic cyber attack techniques to (1) gain a better understanding of the cyber threat and (2) learn the terminology to communicate with more technical IT people – and eventually be able to collaborate across the organization to be better at preventing, detecting, responding to and recovering from cyber attacks.

4.2 Explain the teaching methodology

A common question from learners is: “Why do we have to do this?”. It is always recommended to explain why you have designed the learning experience as you have. When using gamification and challenges, it is particularly important that the learning goals are clear when developing the challenges, and that the learning goals and context is also clear for the learner – it might be fun, but it should be clear for the learning that it is more than that. For example, when learning how a dictionary attack works on a password login, the point is not to master dictionary attacks, but to understand how to create better password policies.

4.3 Active Learning

Training should be based on active learning, rather than simply reading materials or watching videos. Active learning not only improves retention and learning outcomes, but it is also more engaging and fun for the learners. Active learning can take many shapes and forms: Exercises, competitions, discussion sessions, and much more. (Prümmer, van Steen and van den Berg, 2024) recently conducted a systematic review of current cybersecurity training methods and identified seven distinct training methods: Game-based training, presentation-based training, simulation-based training, information-based training, video-based training and text-based training (while also mentioning punishment-based training). While most of these can have active learning elements, our experience is that active learning often evolves around discussions, cases (can focus on human, organizational or technical aspects or a mix of these), gamification, and/or use of formats such as Capture The Flag or other kind of virtual lab scenarios. The latter are widely used in the industry, e.g. HackTheBox (Hack The Box, 2025), Try Hack Me (TryHackMe, 2025), as well as by the companies of the authors (Campfire Security ApS, SagaLabs ApS and ICSRange ApS), and the basic idea is that the learner can get hands-on experience with security/hacking in a closed and secure environment – often based on getting points or succeeding in missions, which together with the resemblance of real situations is very motivating.

4.4 Taking into account different learning styles

There are different theories on learning styles, but the short summary is that different people learn best in different ways. This is something that should always be considered when designing learning materials. One model is that of Neil Fleming: The VARK model (Fleming, 2001), which include four sensory modalities, i.e. visual learning, aural learning, reading/writing learning and kinesthetic learning – while also emphasizing that people might prefer a mix of these. When creating training materials, it is recommended to ensure that as many learning preferences as possible are accommodated - ideally by having some redundancy. For example, making sure that the same concept is explained both visually, by text and by practical assignments.

4.5 Use a well-known framework for measuring learning outcomes

Academia often uses taxonomies such as Blooms taxonomy, which refers to knowledge, skills and competences. While this can be hard to use for shorter trainings – measured in hours or days rather than in months or years – it is recommended to use a well-known framework for formulating learning outcomes – for example the NICE framework (NICE, 2025), or variations of it.

4.6 Role based training – and also collaboration across roles

Training should be designed according to people's different roles, so that the training is both relevant and fit the backgrounds of the learners and the challenges they experience. When working in teams during a training session or a course, the experience should ideally be designed so that people with different roles need to work together – this supports not only team building, but also the ability to collaborate across roles. For example, a challenge could require network knowledge to do network scanning and find a vulnerable service, whereas programming skills would be required to either exploit or patch the vulnerability. There is also a need for thinking across attack (red) and defense (blue) – as to master one side, you also need to understand the other. For this reason, platforms and courses should be designed to train for both sides. This aspect is also underlined in both the NIS2 directive, and in the European Cybersecurity Skills framework (ENISA, 2022).

4.7 Combining theory and practice

The best learning happens when theory and practice is combined, and in general we recommend breaking down the learning blocks in small parts: It of course depends on topics, but in general it is good to have practical/hands-on problems, experiments or cases every time a new tool, concept or method is introduced. This reinforces the learning of this new tool/concept/method and makes the learner ready to build further knowledge on top. People learn differently and have different preferences in terms of learning styles, so the exact pattern and mix of theory and practice will always depend on the individual. An example could be to build training paths with components, where each component contains (1) introduction/theory, (2) practical challenge and (3) reflection/feedback.

4.8 One thing at a time

For many learners who are new to cybersecurity, the initial learning steps can be overwhelming with many words, methods, concepts, and tools. Add on top that the learners also might need to accustom themselves to a new platform, including how to access the materials, different kind of cyber ranges or virtual labs, and point/scoring systems. We recommend that material is designed with this observation in mind, so the learning curve becomes manageable. On the other hand, it is also important that the learners feel they are learning something new: Therefore, it is recommended to think outside the “usual toolbox”. An example of an easy learning curve could be that the first challenge is merely to insert a flag given in the challenge description, the next is to find a flag on a simple website, and the next again to solve a simple challenge that does not require any tools. Thus, the learner will learn a small new step for every challenge and based on this be able to solve more advanced tasks.

4.9 Ease of use

A learning platform or a cyber range should be easy and intuitive to use for the learner. This means that it should be simple for inexperienced users to access resources and navigate the platform or cyber range. If platforms become too unpolished or too complex, the learner may use more energy navigating the platform or cyber range, rather than obtaining the skills and knowledge planned. For example, it should be intuitive which steps to follow for a beginner – especially if the training is without (much) supervision.

4.10 ChatGPT (and other LLMs) safe challenges

ChatGPT and other Large Language Models are amazing for many purposes – including for learning. However, challenges and exercises need to be “GPT Safe” in the sense that they should not be solvable by merely providing the challenge description. It can be just too hard for learners to resist from cheating when easy points are in sight.

4.11 Collaborative learning

Learning together is always a great way of learning: Instead of solving exercises and problems alone, it is recommended to let learners work together. This often leads to good discussions which support the learning process, and situations where learners are helping each other is also good learning for all parties involved. Compared to working individually, it decreases the risk of being stuck and increases motivation and fun for the learner. As a bonus, learners get to know each other better. For most tasks, we recommend working in smaller groups of 2-4 learners, but this depends of course on the tasks at hand. Another way to motivate for collaborative learning would be to give an option of earning badges by helping others.

4.12 Gamification with a clear mission

Gamification is often setup as solving problems and getting points – or in the cybersecurity world to solve challenges and get flags – which then give points. This often works well, and it is impressive to see how much engagement and motivation gamification creates. However, the effects of gamification can be further boosted by working with missions and storylines instead of “just” getting flags or points. For example, building a storyline of infiltrating a malicious actor through their website might be more engaging for the learners than to simply find a website vulnerability (even though the actual task is the same). This principle is not to make the tasks more complex or less explained, but to build the right storylines where the goals are larger than simply getting a flag.

4.13 Clearly described tasks

In the cybersecurity community, there are many implicit understandings. When training people outside of this specific community, it is easy to get lost. A description of an exercise, where the learners were supposed to exploit a samba vulnerability, gain access to a server, and find a file on that server with the name flag.txt, once had the description “Have you ever tried dancing samba? Neither have we, but it might come in handy here”. With this, the learner would have no clue where to start and what to achieve. It might be a fun description for a CTF competition, where part of the competition is to decode that specific language, but it is not suitable in a training context. This principle depends a bit on how supervised the learners are: The more they are expected to work independently, the more important it is that descriptions are clear. It is important to explain “implicit” terminology, like 0-day, SIEM etc. – at least it should always be carefully considered to write out abbreviations in full.

4.14 Hints are important

While some level of frustration is okay, it is important not to be completely blocked without any possibility to advance. That is why hints are important. On the other hand, there is also a lot of learning in figuring things out, and much satisfaction in succeeding with this. This makes it non-trivial to provide the right hints – also, it can be difficult to automatize, since the hints ideally are depending on the individual learner (or group of learners) and their progress. AI and the use of Large Language Models is something that should be considered in this context, as it might be an efficient and scalable way to provide context-based hints.

4.15 A proper debrief

After finishing a course or learning lecture it is important to debrief and go through the learnings. This helps the learner retain what is learned. It is also a good opportunity to collect feedback for future improvements. Examples of debrief questions could be: What were the most important learnings for you from this course? Which new skills did you acquire? How can what you learned be applied in your everyday life, personally and professionally?

4.16 Making achievements visible

It is also important to equip the learners with visible proofs of their achievements such as certificates and/or badges. Not only does it give the user a more satisfactory experience, it also provides a valuable recognition for external purposes, and can be used on e.g. social media and in CVs.

4.17 Taking into account self-efficacy

Self-efficacy is a person's belief in their ability to perform a task or achieve a goal, and plays an important role for both performance and motivation. Some people might start out with a low self-efficacy, making it important to give them positive experiences with their own achievements from the beginning. And for those starting out with a high self-efficacy, it is also important that they can accomplish their expectations. In general, it is just important that the learners can complete the tasks they start out with, instead of being stuck. A particular consequence is that mechanisms should be in place to help everybody starting out at the right level. Also, this is related to having a hint system, so people are not being stuck.

4.18 Real-world context and experience

Design training scenarios based on real-world cybersecurity threats and use cases, using current trends such as ransomware, supply chain attack, and cloud security challenges. This should help the student gain familiarity with concepts that are applicable to real threats. Ideally, the scenarios are as close to the everyday life of the learners as possible – including the use of same or similar systems, software and operating systems.

4.19 Training for the challenges of tomorrow

Cybersecurity is moving fast forward, and threats and challenges evolve. It is important that trainings are updated, and that new trends are quickly incorporated into the training materials. For example, as LLM's have become more common place a new type of attack has appeared called "Training Data Poisoning". Even though this is a new concept, at the time of writing, it should be incorporated into the learning, so learners understand the underlying rules and dangers of the attack.

4.20 Training for incidents

Much training is focused on prevention and detection of cyber-attacks. However, it is equally important also to train for incident management (including both respond and recover), which makes it important to include aspects such as responsibilities, crisis management, communications and human burnouts.

5 Discussion

The principles we have presented have been defined mainly in collaboration between companies and a variety of stakeholders, including the potential learners. There is also an academic involvement, since one of the authors is active in both academia and in one of the involved companies. We believe that the combination of collaboration across companies, academia and other stakeholders to define best practices through exercises and workshops is interesting and valuable: Making efficient and engaging cybersecurity training is simply in everyone's interest. While we believe that community contributions to the body of knowledge is important, we also acknowledge that there are potential commercial interests when involving companies in research like this. As the principles are essentially a synthesis of existing knowledge, experiences, observations and discussions, we would like to further explore how they can be more systematically validated. This could be through larger use studies. The work of the paper has also made it clear that there are many different contexts, settings and goals when it comes to cybersecurity training. Not all principles apply to all situations, and as such they should not be used as a completely check-list of must-do requirements.

6 Conclusion

The lack of cybersecurity competences is one of the biggest challenges when it comes to combating the increasing cybersecurity threats. To address this challenge, there is a strong need for cybersecurity training at all levels – from awareness training for everybody to specialized training for cybersecurity experts and professionals. In this paper, we mainly address the needs for training of IT professionals.

The paper presents 20 principles for cybersecurity training, which reflect good practices. The principles are based on a combination of theoretical knowledge, practical experience, and extensive dialogues with stakeholders from both industry and academia through a number of joint trainings and workshops. We hope that the principles can inspire further dialogue and discussions, and that they also can be used as inspiration for the many organisations working with cybersecurity training.

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Using GEN-AI to support learning in an engineering PBL environment

Miguel Romá¹, J. David Ballester¹, José A. Signes¹, Tomás Martínez-Marín¹, J. Manuel López-Sánchez¹, Víctor Cazcarra¹

¹ Group of signals, systems and telecommunication – SST. University of Alicante, Spain

Email: miguel.roma@ua.es, davidb@ua.es, ja.signes@ua.es, tomas.martinez@ua.es, juanma.lopez@ua.es, victor.cazcarra@ua.es

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Abstract

With the rapid emergence of Gen-AI tools, there has been a widespread fear among faculty that such tools may be used by students as “aids” in the completion of assignments and projects. In the field of engineering education, in particular, it could weaken the expected learning outcomes after the completion of these tasks. Since their use is very difficult to avoid, it seems interesting to look for strategies by which, instead of limiting their use, learning is favoured by redesigning the activities so that, by using them, learning is generated. This proposal presents an ongoing project that addresses the redesign of a series of projects to impact learning by including the use of AI. The proposal presents previous work to determine the characteristics of the new designs as well as preliminary results of the first implementation.

Keywords: PBL; Generative AI.

1 Introduction

The rapid evolution of artificial intelligence, particularly in the domain of generative models, has ushered in a transformative era across numerous sectors, with education being no exception. Generative AI (GEN-AI), characterized by its capacity to autonomously create novel content, presents unprecedented opportunities to reshape traditional pedagogical approaches. Concurrently, Project-Based Learning (PBL) has long been recognized within engineering education as a methodology with significant pedagogical merit, fostering critical thinking, complex problem-solving abilities, collaborative skills, and the practical application of theoretical knowledge to real-world scenarios. The confluence of these two dynamic forces has sparked an emerging interest in exploring the integration of Gen-AI within engineering education, with initial investigations revealing promising avenues for enhancing the learning experience. However, a central challenge remains: how can engineering PBL projects be effectively redesigned to leverage Gen-AI tools in a manner that not only ensures but actively enhances the student learning process? This redesign must navigate the inherent risks of over-reliance on AI and the potential hindrance to the development of fundamental engineering skills. This paper, as a part of an ongoing project aims to address this challenge by exploring the intersection of Gen-AI and engineering PBL, proposing strategies for project redesign and considering the ethical implications of this integration, including preliminary results.

1.1 AI in PBL

According to Zhang & Chang (2024) current explorations into the application of Gen-AI within engineering education highlight its potential to facilitate personalized learning experiences by adapting to individual student needs. It can also provide tailored feedback, assist in generating learning content, and offer support in navigating complex problem-solving scenarios. Literature suggests that the integration of Gen-AI can lead to enhanced project quality, increased depth of understanding, and greater originality in student work. However, the adoption of Gen-AI in educational settings also raises concerns regarding academic integrity, the potential

for algorithmic bias, and the protection of student data privacy. Therefore, a balanced and ethical approach is essential when considering the role of Gen-AI in engineering education.

To effectively integrate Gen-AI while ensuring robust learning in engineering PBL environments, a shift in project focus is necessary. Projects should be designed to prioritize higher-order thinking skills, moving beyond mere execution or information retrieval (Zheng et al, 2024). This involves framing projects around complex, ill-defined problems that require students to define the problem scope, conduct critical analyses, evaluate potential solutions, and synthesize their findings into innovative outcomes. Such projects necessitate that students actively engage with Gen-AI tools to explore different perspectives and generate initial ideas, but the emphasis remains on their ability to critically evaluate and refine these AI-generated suggestions based on their own engineering knowledge and judgment (Royce & Bennett, 2025). Furthermore, PBL projects can be structured to include iterative design cycles, where Gen-AI serves as a valuable tool for exploration and in-depth analysis (Zhang & Chang, 2024). This allows students to test various hypotheses, simulate different scenarios, and refine their solutions based on the data-driven insights provided by AI, fostering a more dynamic and informed design process.

Examining existing implementations of Gen-AI in engineering PBL courses provides valuable insights into effective integration strategies and potential challenges. These cases demonstrate the diverse ways in which Gen-AI can be integrated into engineering PBL. For instance, in electrical engineering courses, AI tools have been used to enhance project quality and depth (Zhang & Chang, 2024). In biomedical engineering, LLMs have facilitated interdisciplinary problem-solving and led to significant research outcomes (Nnamdi et al. 2025). Furthermore, Gen-AI has been shown to foster creativity in design-focused modules (Lee & Tat, 2023). These examples highlight the potential of AI to enhance higher-order thinking by enabling students to tackle more complex problems and explore innovative solutions (Novtiana, Harmanto & Nuaimah, 2025). Observed learning outcomes across these implementations include notable improvements in the quality, depth, and originality of student projects, as well as the development of lifelong learning habits (Zhang & Chang, 2024).

1.2 Risks of using AI in PBL

While the integration of Gen-AI holds promises for enhancing PBL in engineering education, it also presents potential challenges that must be carefully considered. One significant concern is the risk of students becoming overly reliant on Gen-AI tools, which could inadvertently hinder the development of fundamental engineering skills (Basha 2024). If students consistently depend on AI for generating solutions or completing tasks, they may not fully engage with the critical thinking and problem-solving processes that are central to engineering education. Furthermore, the increased use of AI in learning environments could lead to reduced human interaction, potentially impacting the social and emotional learning that is often fostered through collaborative PBL activities (Al-Zahrani 2024). Maintaining opportunities for meaningful peer-to-peer and student-instructor engagement is crucial for a holistic learning experience. Another key challenge lies in the realm of academic integrity. The advanced capabilities of Gen-AI to generate human-like content make it increasingly difficult to detect AI-generated work, raising concerns about plagiarism and the authenticity of student submissions. Addressing these potential negative impacts requires a thoughtful approach to redesigning PBL projects and implementing appropriate assessment strategies. In a more specific way, the risks of using AI in PBL in engineering education can be structured as follows:

- **Risks to academic integrity.** As highlighted by Qadir (2023), there is a significant risk of students misusing AI tools in dishonest or unauthorized ways, such as submitting AI-generated content as their own without proper attribution. The very ability of AI to mimic human writing styles and generate

sophisticated content poses a direct threat to traditional assessment methods specifically designed to evaluate the individual learning and effort of students. This raises serious questions about the validity of certain types of assignments and the overall integrity of academic credentials awarded by universities. Compounding the issue of maintaining academic integrity is the challenge in effectively detecting AI-generated content, leading to potential misclassification of work by students whose writing style may differ from that of native English speakers. Furthermore, AI models are known to "hallucinate" or generate fabricated information. The over-reliance on potentially flawed AI detection technologies can lead to unjust accusations of academic misconduct. If a significant portion of student work is generated by AI and does not reflect actual learning, the value and prestige associated with a university education may be undermined.

- **Impact on cognitive skills and learning.** A significant concern is the potential for diminished critical thinking and problem-solving abilities (Vieriu & Petrea 2025). Students themselves have expressed worries about the negative impact of AI on their critical thinking skills. The ease with which students can obtain information from AI tools might also discourage them from engaging in the deeper cognitive processes necessary for true understanding and long-term retention of knowledge. Furthermore, there is a risk that students may passively accept AI-generated information without subjecting it to critical evaluation (Office, 2024). Moreover, dependence on AI for content generation could potentially limit students' opportunities to develop their own creative thinking and unique perspectives.
- **Ethical and societal concerns.** One prominent issue is the presence of algorithmic bias and the potential for the perpetuation of inequalities. AI algorithms are trained on vast datasets, and if these datasets contain inherent biases, the AI systems will inevitably reflect and even amplify these biases. AI tools can inadvertently perpetuate societal inequalities, potentially leading to discriminatory outcomes in student evaluations, resource allocation, and even the educational content presented (Chanda et al, 2024). Another critical ethical concern revolves around data privacy and security risks associated with students using AI platforms. Finally, the increasing use of AI by students brings to the forefront the ethical implications of a potential lack of understanding and responsibility for AI-generated content (Jie & Kamrozzaman, 2024). The "black box" nature of some AI algorithms, where the decision-making processes are opaque, can contribute to a lack of critical engagement with the generated output. This may foster a passive acceptance of potentially inaccurate or biased information and diminish students' sense of accountability for the work they submit. Chance et al (2025) provide a comprehensive exploration of ethical risks of AI in engineering education.
- **Effects on student well-being and social interaction.** There is a potential for increased isolation and a reduction in face-to-face interaction. Over-reliance on AI may lead to students spending less time engaging in real-world social interactions. This can negatively impact the development of essential interpersonal skills and emotional intelligence (Klimova & Pikhart, 2025). Concerns have been raised about reduced teacher-student interactions and the possibility that AI might become a primary source of support for some students, which may prove to be insufficient due to the lack of genuine empathy in AI interactions (Vieriu & Petrea 2025). Furthermore, the decreased face-to-face interactions and over-reliance on AI could hinder the development of vital interpersonal skills and emotional intelligence.

2 Context

The projects to be redesigned are included in the third and fourth courses of the degree of Sound and Image in Telecommunication Engineering at the University of Alicante. The objectives of these courses are, among

others, "To form specific skills for engineering work through the study of audio-visual production systems", "Students will be concerned about the challenges and social implications of engineering work" and "To be able to solve new and real problems with creativity in a realistic engineering environment". The projects are developed by teams formed by three students (with, occasionally, some teams of two and four students). The most significant sample of the project portfolio includes the following topics:

- Design and implementation of an automatic white balance (AWB) system.
- Design and implementation of an algorithm to perform automatic chroma key effects with shadows management.
- Approach to 3D video generation from 2D video.

All projects share a central open problem (there is no perfect solution), a part of the algorithm is automatic (which implies the need to start from a hypothesis) and the use of MATLAB® as the preferred programming language. Students have time constraints to find the best possible solution to the problem and must make a public presentation of their work and submit a final report. The main assessment tools are based on self- and peer-assessment and are guided by rubrics.

2.1 Identified risks

In the context of this work, the main risks associated with the use of AI tools in the development of the projects are, mainly, the two first ones mentioned in section 1.2. Using the right combination of prompts, Gen-AI tools, such as ChatGPT can provide a code that can be used as, at least, a partial solution to the problem. This use of Gen-AI means avoiding the benefits associated with the PBL model, which is supposed to encourage students to become self-directed learners, effective problem solvers, and critical thinkers. There is the potential risk of avoiding the process of reflection about the problem and possible solution strategies and not going through the learning opportunities that occur in the process of finding solutions to the failures. In addition to presenting as one's own results that are either plagiarized from the literature without the student's knowledge or, at least, the source of the results is unknown. In addition, the ease of obtaining code from Gen-AI systems means that students can deliver complex codes without really understanding what their algorithms are doing. Considering that, in the context of the subjects involved, code generation is a tool (but the process of learning how to generate code is not among their objectives), it could be understood that code generation through AI does not pose a risk. However, although this is partially true, it would be unacceptable to be unaware of how the presented code enables the implementation of the proposed solution to the problem.

3 Strategy for adapting projects to AI

Over recent years, the integration policy for Gen-AI within the assessed projects has progressed through three distinct phases.

- Initially, the utilization of Gen-AI was strictly prohibited, categorized as academic misconduct.
- Subsequently, a conditional allowance was introduced, permitting Gen-AI use provided it was explicitly declared by the student; failure to disclose constituted academic misconduct. Under this phase, assessment rubrics were adjusted to account for AI assistance, leading to heightened expectations for project outcomes.
- The current and final phase permits and actively recommends the use of Gen-AI tools.

Acknowledging the pedagogical imperative of this latter approach, a comprehensive redesign of the projects became necessary. This redesign aims to ensure the achievement of core learning objectives while proactively mitigating the identified risks associated with Gen-AI integration. The structured process undertaken throughout 2024 and continuing into 2025 involves the following stages:

- Strategy definition. A foundational strategy for project adaptation was developed, informed by a systematic literature review and collaborative insights derived from a workshop with engineering educators convened during the PAEE/ALE'2024 conference (Romá & Bofill, 2024).
- Projects adaptation. Guided by the defined strategy, the relevant projects have undergone, or are currently undergoing, systematic modifications to align with the pedagogical goals and address Gen-AI considerations.
- Pilot testing. During the second semester of the 2024-2025 academic year, a pilot test was conducted utilizing one of the adapted projects. The purpose of this pilot was to obtain preliminary insights into the efficacy and student outcomes resulting from the revised project framework.

3.1 Shifting Project Focus

Projects should be designed to prioritize higher-order thinking skills, moving beyond mere execution or information retrieval (Zheng et al., 2024). This involves framing projects around complex, ill-defined problems that require students to define the problem scope, conduct critical analyses, evaluate potential solutions, and synthesize their findings into innovative outcomes. Such projects necessitate that students actively engage with Gen-AI tools to explore different perspectives and generate initial ideas, but the emphasis remains on their ability to critically evaluate and refine these AI-generated suggestions based on their own engineering knowledge and judgment (Paulson, 2025). Furthermore, PBL projects can be structured to include iterative design cycles, where Gen-AI serves as a valuable tool for exploration and in-depth analysis. This allows students to test various hypotheses, simulate different scenarios, and refine their solutions based on the data-driven insights provided by AI, fostering a more dynamic and informed design process.

3.2 Integrating AI as a Cognitive Tool

The integration of Gen-AI as a cognitive tool within engineering PBL can significantly enhance the learning experience when implemented thoughtfully. For research and information gathering, students should be guided on how to use Gen-AI effectively through well-crafted prompts that encourage deeper understanding rather than simple information retrieval (Zhang & Chang, 2024). Gen-AI can also be leveraged for brainstorming and idea generation, acting as a creative partner to explore diverse perspectives and generate initial concepts. However, it is crucial to maintain student ownership of the final design or solution, ensuring that AI-generated ideas serve as starting points for further development and refinement based on their own critical thinking and engineering expertise. In coding-intensive engineering projects, Gen-AI can provide valuable support by generating initial computational frameworks, offering debugging assistance, and suggesting optimizations (Nnamdi et al., 2025). This allows students to focus on the higher-level problem-solving aspects of the project while still engaging with the fundamental coding principles.

3.3 Promoting Critical Evaluation of AI Outputs

A cornerstone of effective Gen-AI integration in engineering PBL is the explicit promotion of critical evaluation of AI outputs. PBL projects should incorporate activities that require students to actively verify the accuracy and reliability of AI-generated information by cross-referencing it with credible sources such as academic literature, industry standards, or experimental data. Furthermore, students should be challenged to identify potential biases within AI outputs and to consider the ethical implications of utilizing such biased information in their engineering work (Hardebolle et al. 2024). Raising awareness about the inherent biases in AI models due to their training data is essential. Finally, projects should encourage students to reflect on the inherent limitations of AI tools and to appreciate the enduring importance of human expertise and judgment in making critical engineering decisions (Habib, 2024). Emphasizing that AI is a tool to augment human capabilities, not a replacement for the nuanced thinking and ethical considerations that define engineering practice, is paramount.

4 Preliminary results

An initial pilot of the redesigned curriculum projects has been conducted utilizing the "design and implementation of an automatic white balance system" project. This project requires students to develop an algorithm capable of adjusting the color temperature of an arbitrary image without associated contextual information. The process necessitates the initial formulation of a hypothesis that objectively defines whether the color temperature of a given image is neutral. Students receive a project guide outlining the objectives, principal stages, submission deadlines, and assessment rubric. In accordance with the defined pedagogical strategy, key modifications implemented in the revised project include:

- **Deeper reflection questions associated with every project step:** The working guide include reflection questions related to the hypothesis, the testing methods to assess algorithm performance and the detection of images in which the algorithm will not work properly.
- **Mandatory AI Interaction Logging:** The requirement to log AI interactions (prompts used, AI responses, and the student's decision-making process with justifications) is now explicitly part of the final report requirements. This directly addresses the need for transparency and focus on the process of using AI.
- **Dedicated AI Log Assessment:** The rubric now includes specific criteria for evaluating the "AI Use Log and Justification," assessing the quality of documentation and the critical analysis behind accepting or modifying AI outputs.
- **Direct Comparison with AI Solution:** A significant addition is the requirement to test the final student-designed system against a "fully AI-created solution". This comparison must analyze performance, interpretability, and strengths/weaknesses, fostering direct critical engagement with AI capabilities and limitations in this specific context.
- **Enhanced AI Reflection:** While a reflection was present in the original project, the rubric now specifies assessing the critical nature of this reflection, including ethical and learning implications.
- **Detailed Rubric:** The inclusion of a comprehensive rubric provides clear expectations for students and grading consistency. It integrates the AI-related components alongside technical requirements like algorithm performance, creativity, and scientific testing.

To evaluate the preliminary outcomes of the revised project, data were gathered from two distinct sources. First, quantitative assessment metrics were established to compare student performance between the original and revised project iterations. Second, qualitative data were collected through informal discussions with faculty colleagues and students participating in the relevant courses. To facilitate a direct comparison of learning outcomes between the two project versions, a dedicated assessment rubric was developed. This rubric focused exclusively on common elements present in the original and the re-designed projects, deliberately omitting criteria explicitly related to the AI integration introduced in the revision:

- **R1. Conceptual Understanding Score:** Assess performance on specific questions embedded in the final report and presentation that target core AWB concepts (e.g., explaining color spaces, detailing algorithm steps, adapting for moving images).
- **R2. Problem-Solving & Design Iteration Quality:** Analyze the evolution from the first design to the final design, specifically looking for evidence in the report about design improvements and troubleshooting.
- **R3. Critical Analysis & Reflection Quality:** Evaluate the depth of the critical comparison report, focusing on students' ability to analyze their own and others' quality of the proposed solution.
- **R4. Originality & Creativity of the solution:** Adapt the creativity assessment to evaluate not just the novelty of the AWB solution itself, but also to the design process and the result presentation stage.

To facilitate efficient application of this comparative rubric, the scoring scale mirrored that used in the primary project rubric provided to students within the project guide. Each criterion was assessed using a four-point achievement scale: 1- Needs Improvement, 2- Developing, 3- Proficient, and 4- Exceptional. Figure 1 presents

a comparison of the average scores for these four rubric categories derived from projects completed in the 2023-24 academic year ($n=11$) and the 2024-25 academic year ($n=12$).

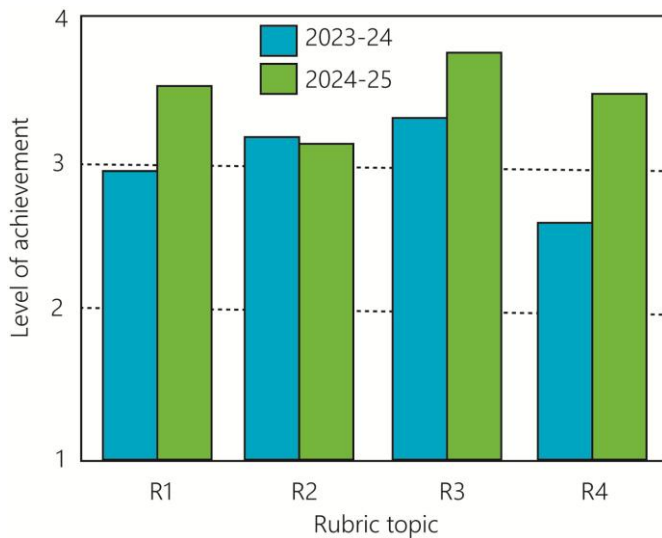


Figure 1. Average values of the rubric topics used to compare the outcomes of the project in 2023-24 and 2024-25.

Although these preliminary findings lack statistical significance due to the limited sample size, they indicate a notable improvement in average scores for criteria R1 (Conceptual Understanding), R3 (Critical Analysis & Reflection), and R4 (Originality & Creativity). In contrast, the average score for R2 (Problem-Solving & Design Iteration) remained largely consistent between the two project versions. This suggests that the integration of more profound reflection questions in the revised project may have positively influenced performance in these areas. Furthermore, the potential for AI tools to facilitate greater efficiency in the coding process might allow students to allocate more time to exploring alternative solutions, potentially contributing to the observed increase in scores for R4 (Originality & Creativity). The improvement in R3 (Critical Analysis & Reflection) is also potentially attributable to the increased emphasis on these competencies within both the project guide and the rubric of the revised project.

Complementing these quantitative data, informal discussions were conducted with faculty members (instructors) and students. Several key themes emerged from this qualitative feedback:

- Instructors reported receiving a higher proportion of student inquiries related to conceptual understanding compared to coding implementation issues, relative to the previous academic year.
- Instructors observed a greater diversity in the solution approaches presented by students in the revised project.
- A concern was raised by instructors regarding the potential underreporting of AI tool usage by students. There was some suspicion that sections of the reflective components might have been generated by AI systems (e.g., ChatGPT), rather than representing original student thought.
- Students expressed engagement with the task requiring comparison of their algorithms against an AI-generated solution, often concluding that their own solutions performed favorably in specific aspects.
- Students indicated an awareness of the potential risks associated with over-reliance on AI tools, acknowledging that excessive use could potentially hinder the development of their independent problem-solving skills.
- Students reported that AI tools enabled them to incorporate advanced techniques (e.g., neural networks) into their projects, even with only foundational prior knowledge in those areas. This was perceived by students as enhancing the overall quality or sophistication of their resulting algorithms.

While acknowledging the preliminary nature of this evaluation, the qualitative feedback from students and instructors aligns with the quantitative data, suggesting that the redesigned project structure may have

resulted in enhanced learning outcomes. It is recognized, however, that further investigation is required to establish the consistency and generalizability of these findings. The redesigned approach needs to be implemented across other projects within the curriculum, followed by a comprehensive analysis, to validate these initial observations.

5 Conclusion

Redesigning engineering PBL projects to effectively integrate Gen-AI tools presents a significant opportunity to enhance both student and teacher learning. The key lies in shifting the project focus towards higher-order thinking skills, promoting the critical evaluation of AI-generated outputs, and emphasizing the use of AI as a tool for exploration and analysis rather than a substitute for student effort. Careful consideration of the ethical implications and the establishment of clear guidelines for responsible AI use are paramount to ensuring academic integrity and fostering the development of essential engineering skills. Future research should explore the long-term impact of AI integration on student learning outcomes and aim to develop best practices for AI-enhanced PBL across various engineering disciplines. Thoughtfully integrated Gen-AI holds the potential to be a transformative force in engineering education, empowering students to become more innovative, critical-thinking, and ethically responsible engineers.

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Robomat Project: attracting young students to STEM areas

Lílian Barros Pereira Campos¹, Dair José de Oliveira¹, Marli Cristina Ferreira², João Paulo Roquim Romanelli¹, Rosa Ferreira Da Silva³

¹ Federal University of Itajubá - Theodomiro Santiago Campos - Itabira - Minas Gerais - Brazil

² Fazenda Betânia State High School

³ Trajano Procópio State High School

Email: liliancampos@unifei.edu.br, dairoliveira@unifei.edu.br, marli.cristina@educacao.mg.gov.br, joaoromanelli@unifei.edu.br, rosa.ferreira.silva@educacao.mg.gov.br,

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Abstract

In Brazil, innovating in public basic education presents significant challenges, particularly when undertaken in contexts characterized by limited resources, low levels of teacher motivation, and complex social conditions—including vulnerability, violence, and exposure to drug-related environments—which may constrain the implementation and sustainability of innovative practices. Attracting students from public schools to higher education, especially in STEM fields, is difficult, with mathematics often intimidating potential candidates. To address this, the Federal University of Itajubá is conducting the "Educational Robotics and Mathematical Thinking" (ROBOMAT) project that is funded by the Foundation for Research Support of Minas Gerais (FAPEMIG). Its primary goal is to introduce the university as a professional training option for students from two public schools in Itabira, Minas Gerais. In this project, 20 students participate in weekly activities at the university. The project activities are facilitated by students from the Drummonsters robotics team. These activities are designed to develop competencies in electronics, mechanics, and programming, as well as transversal competencies such as creativity, communication, resilience, and collaboration. This paper outlines the project's objectives and learning dynamics. To assess the project's impact, data from two data collections are presented. The first data collection, conducted before the project started (May 2024), identified students' expectations and interest in STEM fields, while the second data collection, conducted in December 2024, gathered students' perceptions of their learning after a six-month activities project. Deliverables involved creating a program on the Scratch app that demonstrated mathematical knowledge were analysed in this context. The data analysis revealed key challenges, including motivating students despite external pressures and developing competencies that are unfamiliar to them. So, this paper presents the main challenges of a project that aims to inspire students to pursue higher education and STEM fields by fostering both technical and transversal competencies, while addressing barriers within public education.

Keywords: Active Learning; secondary education; robotics, STEM.

1 Introduction

According to the Brazilian Curriculum Guidelines for High School, issued by the Secretariat of Basic Education of the Brazilian Ministry of Education, the quality of schools is an essential condition for inclusion and the democratization of opportunities in Brazil. Based on this understanding, the challenge of providing quality basic education to support student inclusion, national development, and the consolidation of citizenship is a task for all (MEC, 2006).

In this context, one way universities can contribute to addressing this issue is by acting as catalysts through extension activities that help students expand their knowledge and skills, while also encouraging them to view higher education as a viable path for their future. When such projects take place within the field of Engineering, multiple outcomes can be achieved through the interaction between the academic community and high school students, such as the development of individuals, the dissemination of technology, and the encouragement of young people's interest in STEM (science, technology, engineering, and math) careers (Bacich & Holanda, 2020).

With this in mind, professors from the Federal University of Itajubá – Itabira campus created the project Educational Robotics and Mathematical Thinking in Basic Education, aimed at fostering interaction between faculty and students from the Federal University of Itajubá – Itabira campus and students from two public high schools in Itabira: Escola Estadual Trajano Procópio Alvarenga Silva Monteiro (PREMEM) and Escola Estadual da Fazenda Betânia (EEFB). The project's main goal is to develop STEM-related skills among high school students. This initiative is funded by the Minas Gerais Research Support Foundation (FAPEMIG) under Call 14/2023, with an expected duration from May 2024 to May 2027.

To assess the project's impact, data from two collection phases are presented. The first data collection took place in May 2024, before the project started, through a survey designed to identify students' expectations and interest in STEM fields such as educational robotics, mathematical thinking, engineering, and STEM-related careers. This survey was conducted using physical questionnaires administered to 101 first-year high school students from the two participating schools. The second data collection occurred in December 2024 and aimed to capture students' perceptions of their learning progress up to that point in the project. Additionally, students' reports on a programming challenge were analyzed to assess their competencies in programming, mathematical thinking, and transversal skills such as creativity, collaboration, and communication.

This paper is organized into seven sections. The first section introduces the context and objectives of the paper. Section two discusses the integration of educational robotics and mathematical thinking in Brazilian basic education. Section three presents the study context. Section four presents the materials and methods used. The fifth section presents the results and discussion. The sixth section draws some conclusions. The last section presents the references used in this study.

2 Educational Robotics and Mathematical Thinking in Basic Education

In the context of this paper, the integration of Educational Robotics and mathematical thinking in Basic Education is highly beneficial. When robotics is used for educational purposes, it is referred to as Educational Robotics (ER) (Barbosa et al., 2015). ER is considered a process that extends far beyond the mere assembly of parts, as it fosters changes in attitude, dialogue, cooperation, methodology, questioning, and inquiry among teachers and students, as well as the construction of meaning (Barbosa et al., 2015). In this context, the robot serves as a tool that allows teachers to practically demonstrate complex theoretical concepts—sometimes difficult to grasp—while also motivating students, who are constantly challenged to observe, abstract, and innovate (Barbosa et al., 2015).

Additionally, considering D'Ambrosio's (1996) perspective on reality construction, mathematical thinking can be understood as an essential cognitive ability that emerges from the human need to comprehend, structure, and transform reality. In this view, mathematical thinking is more than just the manipulation of numbers and symbols; it represents a dynamic process of abstraction and logical reasoning, enabling the creation of models, the identification of patterns, and the resolution of complex problems (Pessoa, 2024). For this reason, mathematical thinking is not confined to the use of digits; rather, it permeates all fields of knowledge and daily life, functioning as a tool for both survival and innovation. This broad perspective of mathematical thinking highlights how individuals process information from reality and act upon it, generating a continuous cycle of action and influence that drives change and discoveries beyond their existence (D'Ambrosio, 1996; Pessoa, 2024). In this way, mathematical thinking is not only fundamental in the process of understanding and explaining the world but also enables individuals to transform it, playing a fundamental role in the advancement of science, technology, and human development (D'Ambrosio, 1996; Ellenberg, 2015; Pessoa, 2024).

In this sense, educational robotics and mathematical thinking can be connected, as both promote problem-solving, logical reasoning, and creativity in the learning process. While mathematical thinking provides a foundation for abstraction, pattern recognition, and structured reasoning (Pessoa, 2024), educational robotics serves as an attractive practical application of these cognitive skills, allowing students to experiment, test hypotheses, and refine their understanding through hands-on activities (Barbosa et al., 2015).

This approach is aligned with Brazilian Curriculum Guidelines for High School (MEC, 2006) which recommends that by the end of high school, students are expected to know how to use Mathematics to solve practical problems and to understand the importance of Mathematics for scientific and technological development. In this regard, skills such as problem-solving, critical thinking, communication of ideas, and cooperation need to be developed for the full education of the student (Oliveira, Siqueira, and Romão, 2020) and robotics education can be an effective strategy.

As an example of the integration of educational robotics and mathematical thinking in Brazilian basic education, Da Silveira, Coelho, and Santos (2017) present a teaching experience in Mathematics through the use of a low-cost robot based on the Arduino architecture, with open hardware and software, to work on first-degree functions. Among the proposed activities, students were required to program the robot, check the execution, analyze its behavior, correct errors, and conduct new tests to carry out the proposed tasks. According to the authors, students were active in the knowledge-building process, presenting different levels of difficulty, some of which were related to their lack of familiarity with how robots operate.

Nevertheless, it is important to emphasize that such approaches aim to integrate mathematical thinking with the solution of real dilemmas or more concrete challenges. Seeking this integration of knowledge is considered one of the ways to improve the quality of basic education through increased student engagement, enhanced performance, and mathematical learning (Santos, 2018). It is important to note that teaching strategies are only one of the variables in the teaching-learning process, as the challenges in basic education also involve social and economic aspects (Campos et al, 2024).

3 Study Context

This paper is a product of a study within the scope of the Educational Robotics and Mathematical Thinking in Education project at the Federal University of Itajubá – Itabira campus. This project involves 20 students from two public high schools in the city of Itabira, Minas Gerais State in Brazil: Escola Estadual Trajano Procópio Alvarenga Silva Monteiro (PREMEM) and Escola Estadual da Fazenda Betânia (EEFB).

The project addressed these high schools for some reasons. First, the impact the project can have in terms of representativeness in the municipality and the results for the development of students directly and indirectly involved in the project. The total number of students enrolled in these two schools accounts for 51% of the high school enrollment in Itabira. Secondly, according to data from the Basic Education Evaluation System (SAEB), both schools show unfavorable math learning indicators. At PREMEM, in 2019, 46% of students demonstrated adequate math learning. Considering the Target 3 of the Todos Pela Educação initiative, which states that 70% of students should demonstrate adequate learning, this indicator suggests failure, as less than 50% of students show adequate learning. At this school, the average Brazilian High School Exam (ENEM) score was 542.60, and 60% of graduates took the exam in 2019. ENEM is a nationwide standardized exam used for university admission in Brazil.

Additionally, the situation at EEFB is even more critical. In 2019, only 3% of students demonstrated adequate math learning. This indicates a severe situation and points to the social barriers faced by the community where the school is located. At this school, the average ENEM score was 461.53, and only 26% of graduates took the

exam in 2019. These data highlight the need to support these schools in the critical challenge of providing adequate learning. The project proposal is based on the hypothesis that the initiative can help students develop mathematical thinking to the point of positively impacting the learning indicators set by SAEB.

The project management team consists of three professors from Unifei: an Electrical Engineer, a Mathematician, and an Administrator. Additionally, two high school teachers are involved—one specializing in Biology and the other in Science. The project execution team includes six graduate students selected to work as facilitators, responsible for teaching programming, electronics, and mechanics, which are the core areas of robotics that high school students need to learn.

At the project's inception, it was decided that only 20 first-year high school students could participate due to space limitations in the laboratory where the activities take place. As a recruitment strategy, the management team visited the high schools, briefly introduced the project, and collected data on students' expectations and interest in STEM fields. To select participants, a mathematics test was administered. However, in both schools, only five students took the test, indicating a lower-than-expected level of interest in the project. To fill the remaining spots, the management team accepted an additional five students from each school who expressed a desire to participate, even though they were in their second year of high school.

Project activities began in May 2024. Since then, high school students have attended weekly sessions at the university, where the students are exposed to a combination of content from the regular high school curriculum and new, robotics-specific knowledge. The central objective of the first semester of the program was the development of a line-following robot, a challenge that is a practical application of the theoretical concepts learned. In this sense, the initiative learning objective is to equip them with the knowledge and skills necessary to develop simple robotic solutions to address real-world problems. Table 1 presents the lesson planning for the first semester of the project.

Table 1 - Lesson Planning for the First Semester

Content	Competency
Line Follower	Understand and be able to develop the initial concept of the line follower.
Electrochemistry	Describe the functioning of a battery and its configurations.
Measurement Units and Ohm's Law	Understand the importance of measurement units. Explain the relationships between electrical quantities such as voltage, current, and resistance.
Motor, H-Bridge, Sensor, Battery	Be able to specify a motor, an H-Bridge, a battery, and sensors for a line follower.
Light Propagation and Reflection	Understand the basic concepts of light and the operating principle of sensors used in a line follower robot.
Programming	Understand the concept of algorithms, logical and mathematical operations, and data input and output.
Introduction to the ESP32 Microcontroller	Understand the basic characteristics and applications of the ESP32, including its programming and communication interfaces.
Prototype Assembly	Assemble the mechanical components and electronic circuit of the line follower.
Project Adjustments	Optimize parameters to reduce the lap time of the line follower.
Competition	Interact with peers and exchange experiences between teams.

4 Materials and Method

This paper presents the report of two data collection phases. The first phase took place prior to the start of the project activities, and the second one occurred five months into the project. In the initial phase, an exploratory survey was conducted (GIL, 2002). A total of 101 first-year students from high schools in Itabira participated in this phase, including 71 students from PREM and 30 from EEFB. In the second phase, 8 students from

PREMEM and 2 from EEFB were involved. This phase also included a qualitative analysis of students' reports on a programming challenge, which required them to apply both math and programming knowledge. From these reports, insights were gained into students' perceptions of their learning progress throughout the project. Table 2 shows the number of students involved in the data collection phases of this study.

Table 2. Number of students per data collection phase

Data collection phase	Date	PREMEM Students	EEFB Students
Expectations and interest in STEM fields	May 2024	71	30
Perceptions of their learning progress	December 2024	8	2

In the first part of data collection, the objective was to identify students' expectations regarding the project, as well as their level of interest in educational robotics, mathematical thinking, and STEM-related careers. Data were collected using physical questionnaires administered to first-year high school students from both participating schools. The questionnaire consisted of five questions. The first three gathered demographic information, including identification, gender, and age. Question four asked students to indicate their level of interest in three areas: a) STEM fields (science, technology, engineering, and mathematics); b) participation in projects involving robotics and robotics combined with mathematical thinking; and c) future academic aspirations, such as enrolling in technical education, taking ENEM exam, and studying at Unifei (the university where the project is executed). To answer these questions, a five-point Likert scale was used, where 1 represented no interest and 5 represented high interest. Question five asked students to list their preferred professions. The questionnaire was administered during a visit to the schools after a brief presentation by the project team. No specific details about the project's execution were shared to ensure that students' responses remained unbiased by prior information.

In the second part of data collection, students were asked to write a report about a programming challenge they participated in. This challenge was called Digital Safe in Scratch Platform. The object of the challenge was to engage students in programming and logical reasoning by having them create a password validation system. In the first phase, each student individually defined three custom rules for a three-digit code and implemented them in Scratch Platform, using variables and conditional statements. It was expected that the program prompted the user to input numbers, to check if they met the rules, and to display whether the password was valid or invalid. In the second phase, students paired up to test each other's programs by attempting to bypass the rules and then collaborated to create a more complex digital safe with a four-digit code and challenging new rules. After implementing the new program, the pairs presented their solutions, explained their reasoning, and challenged their peers to crack the code. This challenge aimed to foster creativity, problem-solving, and teamwork while promoting computational thinking.

The student reports were analyzed to identify their perceptions of learning and progress up to the fifth month of the project.

5 Results and discussion

The characterization of the students who responded to the first data collection is presented in Table 3. In this sample, 56% were male, 43% were female, and 1 person self-identified as another gender, as shown in Table 3.

Table 3 - Demographic characterization of the surveyed students - gender

Gender	Quantity of students	Percent
Female	43	43%
Male	57	56%
Other	1	1%

Regarding the students' age, 87 students were in the 15 to 16-year-old range, while the remaining students were in the 17 to 18-year-old range (Table 4).

Table 4 - Demographic characterization of the surveyed students - age range

Age range	Quantity of students	Percent
15-16	87	86%
17-18	14	14%

To analyze the students' areas of interest, the percentage of students with high interest in the topics surveyed is tabulated below, meaning students who answered 4 or 5 on the proposed interest scale. The students were asked about their interest in STEM fields: science, technology, engineering, and mathematics. Regarding technology interest, two questions were posed: one about interest in using technology and another about interest in learning how to develop technology. As shown in Figure 1, 84% of students reported a high interest in using technology, while 78% expressed interest in learning to develop technology. It is worth noting that the 6 percentage point difference between these two perceptions regarding technology in this sample highlights the particularity of Generation Z, who, as digital natives, make intensive use of technology but do not necessarily have an interest in engaging in technological development.

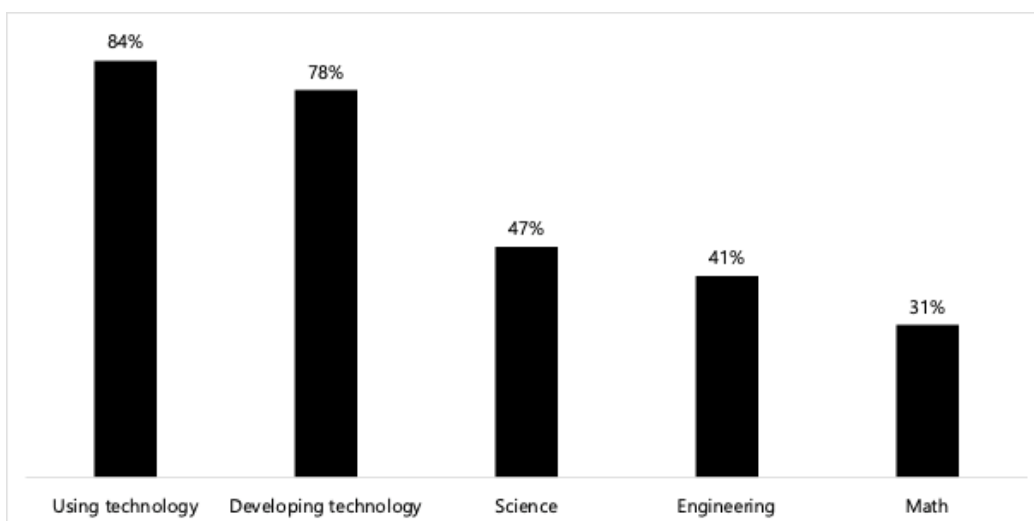


Figure 1: Percentage chart of students with high interest in STEM fields.

In descending order, the interest in sciences (47%), engineering (41%), and mathematics (31%) was observed. This scenario reflects the Brazilian reality of a growing disinterest in exact sciences, highlighting the need for actions to promote and value these areas of knowledge, which are crucial for the future of work (IFTF, 2017; UNESCO, 2018; Neto & Batista, 2020; Foscaches et al., 2023).

To assess students' interest in the specific field of robotics, they were asked about their willingness to participate in two types of projects. The first involved robotics, and the second combined robotics with mathematical thinking. As shown in Figure 2, 35% of students expressed high interest in robotics, while 48% showed interest in participating in projects on this topic. Regarding the option of participating in a project involving both robotics and mathematical thinking, 30% of students expressed high interest.

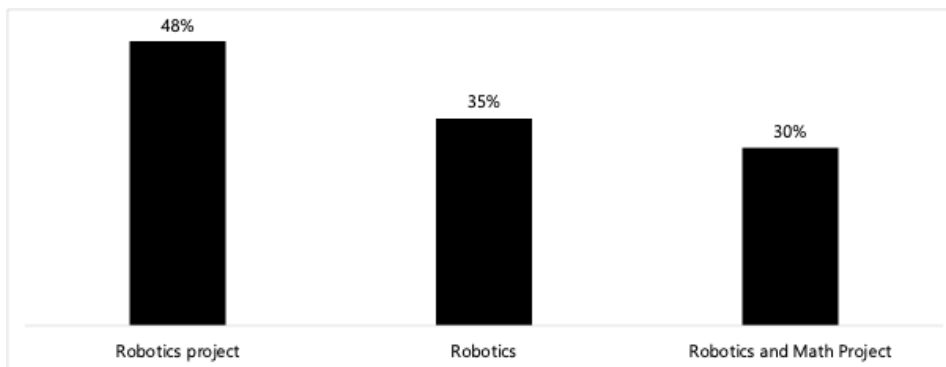


Figure 2: Percentage of students with high interest in a robotics project, robotics and robotics and math projects.

This result may indicate students' aversion or even fear towards mathematics, considering this area of knowledge as difficult and unpleasant (Prediger, Berwanger & Mörs, 2013). This reality points to the need to present mathematics in a way that is connected to the student's reality, using areas of their interest, so that this field of knowledge becomes relevant for solving issues that are meaningful to the student.

Regarding expectations for continuing their studies, students were asked about their intentions to enroll in a technical course, take the ENEM, and study at Unifei. Figure 3 shows the responses to these questions. 78% of the students expressed interest in pursuing a technical course, 67% expressed interest in studying at Unifei, and 60% reported interest in taking the ENEM.

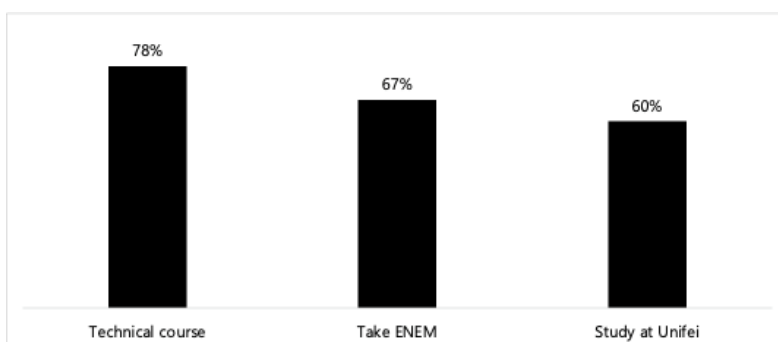


Figure 3: Percentage of students with high interest in taking a technical course, taking ENEM, and studying at Unifei

When asked about their specific interest in participating in the Educational Robotics and Mathematical Thinking project, 47% of the students said yes. Of this group, 21 students were female, 26 were male, and 1 self-identified as another gender.

The analysis of the students' responses regarding their career interests revealed a diverse range of aspirations, with a strong emphasis on STEM-related fields. Professions such as engineering, medicine, computer programming, and biotechnology appeared frequently, indicating a significant level of interest in technical and scientific areas. Additionally, careers in law and biomedical science were also commonly mentioned, reflecting a blend of both human sciences and business-oriented interests. The presence of creative and less conventional roles like YouTuber, pilot, and illustrator suggests that students are also exploring modern and dynamic career paths influenced by current technological and cultural trends.

Table 5 - Student's reports characteristics - quality and content

#	Reports Quality	Content	High School
Report 1	This report was well-written and effectively highlighted the opportunities students had to enhance their programming and problem-solving skills.	Challenge description and declaration of knowledge access during the learning activity (mathematics thinking and programming)	PREMEM
Report 2	The report was overly simplistic, lacked proper formatting, and it presented the content in a superficial manner.	The students highlighted that they use factorials, multiplication, and division. They reported that completing the challenge was difficult and they expressed gratitude for the opportunity to participate in a highly valuable experience	EEFB
Report 3	The report was overly simplistic, lacked proper formatting, and it presented the content in a superficial manner.	Challenge description and explanation of reasoning they got in the challenge.	PREMEM
Report 4	This report was well-written and effectively highlighted the opportunities students had to enhance their programming and problem-solving skills.	Challenge description and declaration of knowledge access during the learning activity (mathematics thinking, programming, creativity and logical thinking).	PREMEM
Report 5	This report was well-written and effectively highlighted the opportunities students had to enhance their programming and problem-solving skills.	The report mentioned the opportunity to explore an area of innovative development, offering different perspectives on the technology and how it impacts everyday contexts.	PREMEM

The five student reports varied in quality. Some students, particularly from PREMEM, demonstrated stronger writing skills by clearly describing the challenge, its development process, and the key learning outcomes. On the other hand, all reports highlighted not only elements of mathematical thinking but also the transversal skills that were engaged throughout the challenge. As the students highlighted these learning outcomes, it can be inferred that the project has been effective in integrating mathematical thinking and programming skills. Given that the project has been running for only six months, it is crucial to continue monitoring its results to assess its long-term impact on participants' knowledge.

6 Conclusions

The data from this study on the Educational Robotics and Mathematical Thinking Project reveal both the potential and challenges of engaging high school students in STEM-related extracurricular activities. Despite an initial recruitment of 101 first-year high school students, only 47 expressed interest in participating and 10 enrolled in the selection phase. Since the project management team decided to offer 20 spots, an additional 10 second-year high school students who expressed interest in the project were admitted. However, only 10 were present at the programming challenge proposed six months into the project. These facts illustrate the significant challenge of maintaining student engagement in projects driven solely by intrinsic motivation, without financial incentives.

The findings also indicate a high interest in using technology (84%) and developing it (78%), although interest declines in fields like science (47%), engineering (41%), and mathematics (31%). This gap underscores a broader societal trend of disengagement from mathematics and exact sciences in Brazil. Moreover, while 35% of students showed interest in robotics, only 30% were eager to engage in projects combining robotics with mathematical thinking, suggesting potential apprehension toward mathematics. The varied career aspirations—ranging from STEM fields to creative and modern roles—highlight the diverse interests of Generation Z and the need for adaptable, interest-driven educational approaches.

Despite the limited number of students who participated in the proposed challenge, all the reports analyzed showed the integration of mathematical thinking and knowledge related to robotics. It is also noticeable that all the reports mention transversal competencies that students recognize as being developed during the project, such as logical reasoning, creativity, and collaboration.

Research limitations include the small sample size that reached the final stages of the project, potential self-selection bias, and limited longitudinal data to assess long-term impact. Additionally, the analysis of only five student reports restricts broader generalizations about learning outcomes. Future research should explore strategies to enhance student motivation, perhaps through incentives or stronger integration with formal education. Longitudinal studies with larger, more diverse cohorts are also needed to assess sustained impact and refine approaches to presenting mathematics in ways that resonate with students' realities and interests.

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Collaborative And Integrated Planning for the Institutional Introduction of Active Methodologies in Engineering Education

Liliane Fonseca¹, Sergio Campello¹, Andrea Ribeiro²

¹ University of Pernambuco, Brazil

² Federal University of Pernambuco, Brazil

Email: liliane.ssilva@upe.br, Sergio.campello@upe.br, andrea.marianogueira@ufpe.br

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Abstract

Higher education in Brazil has traditionally been structured around discipline-based courses. Since 2019, with the implementation of competency-based assessment frameworks, Higher Education Institutions (HEIs) have been required to redesign their instructional strategies to promote interdisciplinary integration and competency development. This paper investigates the use of a canvas-based approach as a collaborative planning tool for faculty members. The study demonstrates how the canvas supports curriculum integration and the adoption of active learning methodologies in engineering education. Case studies were conducted to evaluate the effectiveness of collaborative planning involving both interdisciplinary course integration and cooperation among multiple instructors teaching the same course across different sections. Results show that canvas-supported planning significantly contributed to enhanced curricular cohesion, improved quality of course syllabi, and increased student engagement. The findings suggest that the use of canvas and digital collaboration tools enhances the teaching and learning process. Moreover, this approach can serve as a strategic framework for ongoing institutional transformation, fostering the implementation of active methodologies and continuous curricular integration.

Keywords: Active Learning; Engineering Education; Curriculum Integration; Collaborative Planning

1 Introduction

Engineering education in Brazil faces significant challenges, particularly within an educational context that demands the development of professionals equipped with both technical expertise and socio-emotional skills. However, traditional pedagogical practices—often fragmented and content-driven—fall short in meeting the demands of a profession that increasingly requires engineers capable of teamwork, effective communication, and rapid adaptability to change (Kolb, 2015). For years, engineering programs have struggled with issues of student retention and dropout rates. A new challenge has now emerged: student attraction. According to recent data from the national higher education census, enrollment in distance learning programs has surpassed that of traditional in-person programs. The same report indicates a graduation rate below 40% and a surplus of unfilled seats across various engineering programs nationwide (INEP, 2024).

In this scenario, active learning methodologies have emerged as an effective response to engage students and promote more meaningful and contextualized learning. These methodologies offer a viable approach to mitigating dropout and retention issues while also enhancing student attraction. By promoting student agency, active learning facilitates the development of essential competencies such as problem-solving, creativity, and innovation (Bonwell & Eison, 1991). However, the effective implementation of such methodologies requires careful and collaborative planning among faculty members. This planning must ensure alignment between proposed activities and learning objectives, while also integrating appropriate technologies and digital resources to enhance the teaching and learning experience. Despite their proven benefits, active methodologies remain underutilized—primarily due to inadequate faculty training and infrastructural limitations (Prince, 2004).

In this context, the present study proposes and evaluates the use of a canvas framework for collaborative and integrated instructional planning, aimed at supporting the institutional implementation of active learning methodologies in engineering education.

2 Literature Review

Active learning methodologies have emerged as essential approaches to promoting more engaging and meaningful learning experiences in engineering education. The concept of meaningful learning implies that content must be relevant and make sense to students, ensuring its applicability in practical contexts. Studies such as Freeman et al. (2014) have shown that these methodologies improve academic performance and increase knowledge retention, particularly in areas that demand problem-solving skills, such as engineering.

Among the most widely used active learning methodologies in engineering education are Problem-Based Learning (PBL), Project-Based Learning (PjBL), and Challenge-Based Learning (CBL). These approaches engage students in tasks that simulate real-world problems, fostering the application of theoretical concepts to practical situations. Furthermore, active methodologies require students to take on a more proactive role in the learning process, which, according to Prince (2004), contributes to the development of essential competencies such as communication, teamwork, and adaptability to new technologies and processes.

2.1 Collaborative Planning for Competency Development

Collaborative planning has proven effective in business environments, exemplified by tools such as the Business Model Canvas (Osterwalder & Pigneur, 2011) and the Project Model Canvas (Finocchio, 2013). These visual frameworks simplify communication, promote collaboration, and facilitate goal alignment, allowing key elements of business models to be identified and adjusted to ensure a shared understanding among all stakeholders. Translating these concepts to engineering education opens the opportunity to apply collaborative planning to address educational challenges. Margot and Kettler (2019) emphasize that integrating disciplines and fostering collaboration among faculty within a curriculum not only enhances content comprehension but also promotes its practical application, which is essential for solving complex problems in multidisciplinary fields such as engineering. In this context, the notion of competency proposed by Zabala (1999) becomes highly relevant, defining competencies as the combination of procedures, knowledge, and attitudes.

Collaborative planning enables faculty to align content and competencies across different courses, fostering a more cohesive and interconnected curriculum. This alignment supports the development of competencies in accordance with the Brazilian National Curriculum Guidelines (DCNs). Collaborative planning allows for the creation of multidisciplinary activities involving instructors from various engineering disciplines, thereby preparing students for real-world work scenarios that require cross-disciplinary integration. In the implementation of active methodologies, collaborative planning supports coordination across courses, enabling the design of interdisciplinary projects and the application of active approaches. Moreover, student motivation and engagement are enhanced when instructors design activities that connect different subjects, as students are better able to perceive the relevance of course content and its practical applications. Traditionally, curriculum matrices aim to organize the distribution of content by semester through different courses. Some content is essential for future courses, while other topics may complement subjects offered during the same period. Effective planning, therefore, requires collaboration among faculty members teaching in the same semester and coordination across sequential courses in different periods. There is also the potential for cross-program planning, where a course with similar content is taught in multiple degree programs within the same institution.

2.2 Planning Tools in Engineering Education

For collaborative planning to be effective, it is crucial to use tools and techniques that facilitate communication and information organization. One of the most prominent tools in the literature is the canvas, a visual mapping technique that structures information in an organized way, supporting the planning, analysis, and understanding of a specific situation (Card, Mackinlay, & Shneiderman, 1999). In the context of engineering education, the canvas is particularly useful as a collaborative planning tool, as it allows faculty to align learning objectives and organize their courses clearly and visually. The use of a canvas enables instructors to collaboratively design and analyze their courses, ensuring that all essential elements are considered and discussed collectively. This approach supports course integration and the effective implementation of active methodologies, while also simplifying communication among faculty and allowing for the continuous review and adaptation of teaching plans (Osterwalder & Pigneur, 2011; Finocchio, 2013). However, adopting a canvas—literally a visual board—does not guarantee the desired interactivity. Success depends on the adoption of a visual model with well-structured divisions and planning guides that support instructional design.

Collaborative digital tools have proven especially valuable in the digital application of canvas-based frameworks. These platforms allow faculty to share resources, collaborate in real time, and integrate activities across courses, contributing to a more cohesive and student-centered learning environment. Rosa and Carvalho (2021) emphasize that the use of digital collaboration tools simplifies joint planning, enhances interactivity, and promotes the exchange of ideas among instructors, resulting in more coherent and integrated teaching strategies.

In addition to facilitating collaborative planning, the use of the canvas allows instructors to clearly visualize where and how active learning methodologies will be applied at each stage of the course. For example, when filling out the “Teaching and Learning Methodology” section, instructors are guided to select approaches such as PBL, CBL, or flipped classroom and to justify how these strategies will support the defined learning objectives. The canvas’s integrated visual structure contributes to coherence between competencies, methods, and assessments—an essential aspect for the effective implementation of active learning methodologies.

3 Methodology

The development of the canvas for collaborative planning in engineering education was inspired by visual mapping approaches, such as the Business Model Canvas and the Project Model Canvas.

Adapted to the educational context, the canvas—illustrated in Figure 1—was structured to emphasize the main areas of student competency development, allowing engineering instructors to collaboratively plan their courses in alignment with the Brazilian National Curriculum Guidelines (DCNs).

The canvas was designed to be a flexible tool, capable of adapting to different courses and educational settings. It consists of eleven sections, as shown in Figure 1. Each section includes guiding questions that assist instructors in completing the course plan in a structured and reflective manner.

To support the implementation of the instructional planning canvas and to promote collaboration among faculty, a comparative analysis of various digital collaborative tools was conducted. However, to make the process more accessible to instructors, the canvas may also be used in a printed version, using sticky notes (post-its) to fill in the various components. This traditional approach allows educators to become familiar with the canvas structure, emphasizing interaction and idea exchange while postponing the digital learning curve to a later stage.

Canvas for Collaborative Teaching Planning

The collaborative planning canvas is a structured tool designed to assist educators in developing integrated and cohesive teaching plans. This canvas covers all essential aspects of pedagogical planning, from defining learning objectives and competencies to selecting teaching methodologies, digital technologies, and assessment criteria. Each section of the canvas includes guiding questions to facilitate completion and promote collaboration among educators, ensuring that all subjects align with institutional expectations and the needs of students.

Course Describe the course: field of study, modality, name, code, class hours, duration, and prerequisites.				Objectives Define general and specific learning objectives to guide content delivery.			
What is the course name?	What is the total and weekly workload?	What is the modality and duration?	Are there prerequisites to this course?	What are the general learning objectives?	What are the specific learning objectives?		
Competencies Define expected general and specific competencies (technical and non-technical), and learning outcomes.		Teaching and Learning Methodology Define active teaching methods such as PBL, flipped classroom, design thinking, etc.		Digital Technologies and Resources Define interactive tools and resources to support learning and engagement.		Learning Components Outline curricular units, their topics, and workload.	
What are the expected competencies?	What are the learning outcomes?	What teaching and learning methods will be used?	How will these methods foster active and authentic learning?	What technological and digital resources will be used?	How will these methods foster active and authentic learning?	What are the main curricular units?	What content will be covered in each unit?
						How will the workload be distributed?	
Infrastructure Specify physical and virtual infrastructure, including software and equipment.							
Assessment of Learning Establish assessment rubrics: criteria, weight, and scoring methods.				Success Indicators Define indicators for evaluating student learning and instructional effectiveness.		Schedule Define the weekly plan, dates for assessments, and feedback.	
What are the assessment criteria?	How will the rubrics be structured?	What are the success indicators for the course?	How will student performance be evaluated?	How will instructor performance be evaluated?	What metrics will be used?	What is the weekly class schedule?	When will assessments and assignments take place?
						How will feedback be gathered throughout the course?	
References List required and complementary bibliography and additional learning materials.							
What are the basic references?	What are the complementary references?	What support resources will be available to students?					
Some Suggestions for Digital Technologies and Resources							
Quiz and Assessment Tools 		Real-Time Response Tools 		Presentation and Interactivity Tools 		Drawing and Creativity Tools 	
						Collaboration and Feedback Tools 	
						Time Management Tools 	
Some Suggestions for Physical Tools							
Canvas	Post-its	Colored Pens and Markers	Whiteboard and Flipchart	Planning Pockets	Prototyping Kits: LEGO, clay, popsocket sticks, among others, used to create physical prototypes.	Notepad and Notebooks	

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Figure 1. Canvas for Collaborative Instructional Planning in Engineering Education. Source: elaborated by the authors.

The transition from the paper-based canvas to a digital environment can occur gradually, as faculty members become more confident and comfortable with the process. The digitization of the canvas can then be carried out using digital platforms that support real-time collaboration and allow for continuous and dynamic monitoring of instructional planning. Additionally, the use of these digital tools enables the integration of other resources and the creation of a collaborative history accessible to all participants, ensuring that the work developed can be easily revisited and adjusted as needed. Table 1 presents the sections, descriptions, and guiding questions contained in the canvas. The digital canvas was developed using the Miro digital tool. Recent studies reinforce the role of digital tools in promoting pedagogical innovation and active learning. Røe, Wojniusz, and Bjerke (2021) highlight how digital transformation in higher education enables instructors to implement active learning strategies more effectively through technology-supported environments.

Table 1. Canvas for Collaborative Teaching Planning

Section	Description	Guiding Questions
Course	Describe the course: field of study, modality, name, code, class hours, duration, and prerequisites.	- What is the course name? - What is the total and weekly workload? - What is the modality and duration? - Are there prerequisites for this course?
Objectives	Define general and specific learning objectives to guide content delivery.	- What are the general learning objectives? - What are the specific learning objectives?
Competencies	Define expected general and specific competencies (technical and non-technical), and learning outcomes.	- What are the expected competencies? - What are the learning outcomes?
Teaching and Learning Methodology	Define active teaching methods such as PBL, flipped classroom, design thinking, etc.	- What teaching and learning methods will be used? - How will these methods foster active and advanced learning?
Digital Technologies and Resources	Define interactive tools and resources to support learning and engagement.	- What technologies and digital resources will be used? - What tools will promote interactivity and student participation?
Learning Components	Outline curricular units, their topics, and workload.	- What are the main curricular units? - What content will be covered in each unit? - How will the workload be distributed?
Infrastructure	Specify physical and virtual infrastructure, including software and equipment.	- What are the physical infrastructure requirements? - What software and equipment will be needed? - How will the classroom be organized to support active learning?
Assessment of Learning	Establish assessment rubrics: criteria, weight, and scoring methods.	- What are the assessment criteria? - How will the rubrics be structured?
Success Indicators	Define indicators for evaluating student learning and instructional effectiveness.	- What are the success indicators for the course? - How will student performance be evaluated? - How will instructor performance be evaluated? - What metrics will be used?
Schedule	Define the weekly plan, dates for assessments, and feedback.	- What is the weekly class schedule? - When will assessments and submissions take place? - How will feedback be distributed throughout the course?
References	List required and complementary bibliography and additional learning materials.	- What are the basic references? - What are the complementary references? - What support materials will be available to students?

Two case studies were conducted to evaluate the effectiveness of the instructional planning canvas. The first case study took place within the Computer Science program and involved collaborative and integrated planning among instructors in two distinct scenarios: Scenario 1, where different instructors taught the same

course in separate sections, and Scenario 2, where instructors from different courses collaborated to design interdisciplinary projects. Case Study 1 was carried out at the Catholic University of Pernambuco (UNICAP) and covered the academic terms 2023.1, 2023.2, and 2024.1. Initially, in 2023, thirteen instructors were trained using a physical version of the canvas to collaboratively plan the first-semester courses. In 2024, twenty instructors transitioned to using the digital canvas on the Miro platform. The effectiveness of the canvas was evaluated based on the quality of the instructional plans developed, the ease of use reported by the faculty, and the level of collaboration achieved in the two scenarios, measured at the beginning and end of each semester.

Case Study 2 was conducted during the academic terms of 2023.2, 2024.1, and 2024.2 in courses from the Computer Engineering program at the University of Pernambuco. This study aimed to assess students' perceptions of active learning in engineering education. In total, four courses were planned and evaluated in 2023.2, and an additional four in 2024.1, with 213 students participating in the course evaluations.

In addition to document analysis and review of the instructional plans developed, students' perceptions of active learning methodologies and digital technologies were assessed through a structured survey. Participants were students regularly enrolled in courses that adopted the canvas-based planning approach during the evaluated semesters. All students in these courses were invited to respond voluntarily and anonymously, with no impact on their academic evaluations. The instrument consisted of an online questionnaire administered at the end of each academic term. It included 10 statements rated on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree), addressing topics such as clarity of learning objectives, course organization, the use of active methodologies, engagement with digital tools, and perceived learning outcomes. The questions were designed based on prior studies in active learning and competency-based planning to ensure content validity. Data collection always occurred after the implementation of the planned activities, aiming to capture students' perceptions following the complete learning experience. The response rate was approximately 85% of enrolled students. Table 2 provides a summary of the survey methodology.

Table 2. Summary of Survey Methodology

Aspect	Description
Type of instrument	Online questionnaire with Likert scale (1–5)
Number of items	10 statements
Sample	213 engineering students
Period of application	End of semesters 2023.2, 2024.1, and beginning of 2024.2
Estimated response rate	85%
Selection criteria	Courses planned using the canvas and taught by volunteer instructors
Platform used	Institutional form (Google Forms)

The questionnaire consisted of 10 statements distributed across five categories: clarity of learning objectives, instructional organization, application of active methodologies, use of digital technologies, and students' self-perception of engagement. Table 3 presents the statements used in the questionnaire to assess students' perceptions regarding the use of the canvas and active methodologies. All items followed a 5-point Likert scale format (1 = Strongly disagree, 5 = Strongly agree).

Table 3. Statements Used in the Questionnaire

Category	Statement
Clarity and Course Organization	The learning objectives were clearly presented at the beginning of the course.
	The organization of the classes helped me understand the course content.
Active Methodologies	The proposed activities required my active participation in the learning process.
	The adopted approach supported the development of competencies required in the course.
Digital Technologies and Resources	The use of digital tools (such as collaborative boards, online platforms, simulators, etc.) facilitated my learning.
	The technologies used made the classes more interactive and dynamic.
Curricular Integration and Interdisciplinarity	I was able to perceive connections between this course and other courses in the program.
	The activities addressed real-world or professional practice problems.
Student Engagement and Learning Experience	I felt motivated to participate in the classes due to the strategies adopted.
	The learning experience in this course was enriching and contributed to my academic development.

4 Results and Discussion

In the first study, faculty members began using the physical version of the canvas in 2023 for collaborative instructional planning, transitioning to a digital platform in 2024. Although the transition presented initial challenges—such as adapting to the new format—instructors reported a significant improvement in usability and planning cohesion over time. By the end of the semester, 90% of the faculty indicated that the canvas was essential for achieving greater integration and collaboration in course planning. It is important to note that the only negative feedback referred to the time and effort required for adaptation and integration. In the second study, the adoption of the digital canvas resulted in more structured and consistent planning. The positive adaptation to the digital platform facilitated effective organization of course content, confirming the canvas as a central tool in the instructional planning process.

The positive impact of the canvas on curriculum integration was evident in the first study. During the 2023 and 2024 academic terms, its use enabled clear alignment of expectations among faculty members, particularly in defining learning objectives and coordinating activities across different courses. With 95% of instructors reporting that the canvas helped to better integrate course content, the data suggest that the canvas was essential to achieving curricular cohesion in the first semester. Furthermore, the analysis of course plans showed increased consistency in the distribution of content and the use of active learning methodologies—factors that were perceived as positively contributing to student development. This resulted in a more widespread adoption of such methodologies.

The evaluation of active learning strategies and the use of digital technologies yielded positive results: 82% of the 213 students surveyed stated that these methodologies significantly contributed to their learning, and 92% approved of the use of digital resources, which enriched their overall educational experience. The analysis of the case studies reinforces the effectiveness of using the canvas as a central tool for collaborative instructional planning, particularly in promoting curriculum integration and improving the quality of course planning. The canvas proved to be essential for structuring and guiding the planning process—both in its physical and digital formats—by facilitating cohesion across courses and aligning learning objectives.

The transition from the physical to the digital canvas format was especially beneficial, as it expanded the scope of collaboration regardless of geographic location. This shift allowed faculty to engage more flexibly and consistently in the planning process, enhancing both participation and the depth of collaboration. These findings are consistent with the literature on digital transformation in higher education, which emphasizes the need for pedagogical strategies that integrate technology to enhance engagement and learning outcomes (Røe et al., 2021).

When comparing these findings to other experiences reported in the literature, it becomes evident that the use of digital tools in collaborative planning is not only effective but also a growing trend across educational domains. Studies such as Rosa and Carvalho (2021) highlight the importance of such technologies in improving curriculum integration and increasing faculty engagement in the planning process.

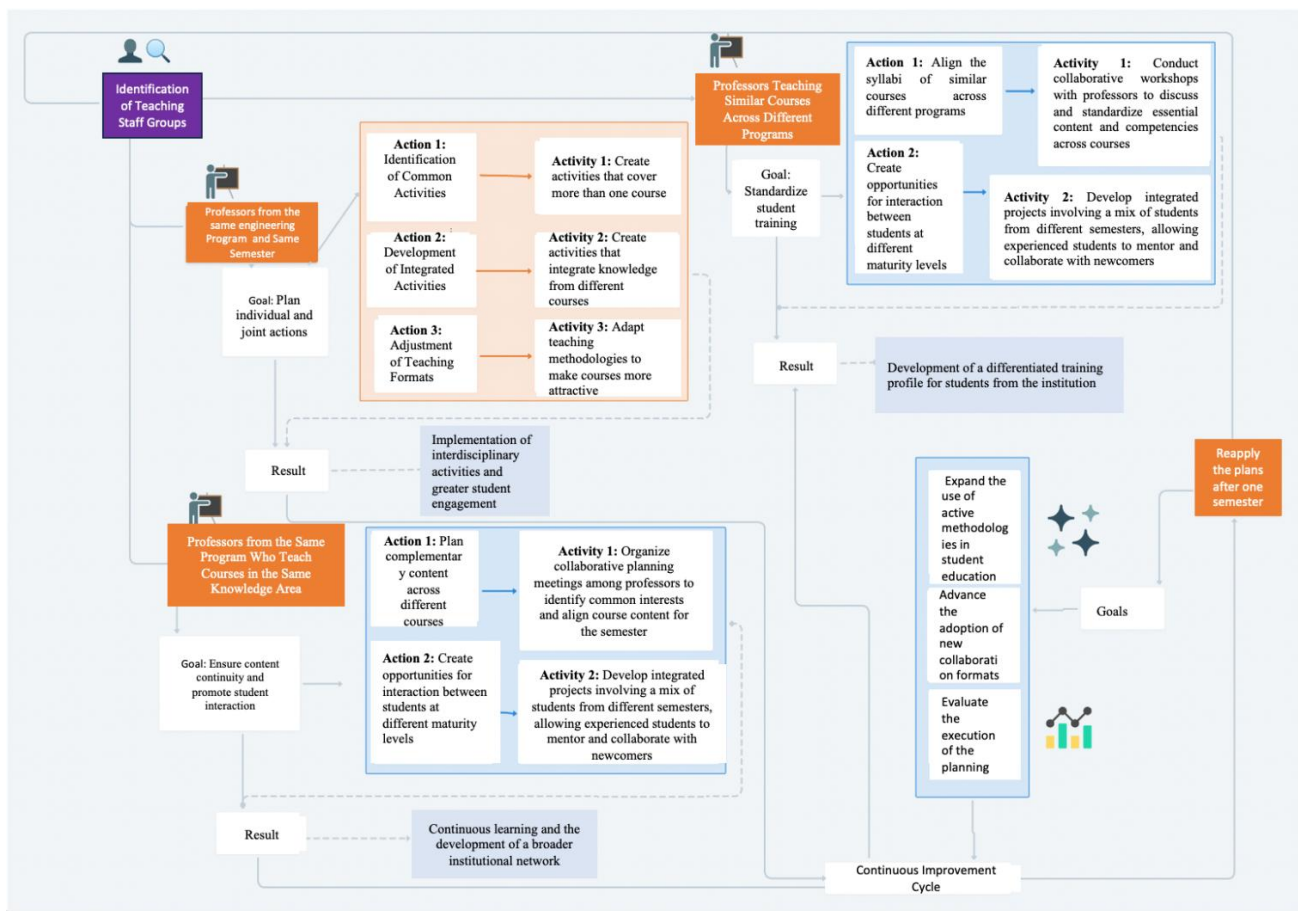


Figure 2. Flowchart of the application of canvas-assisted planning

The canvas also facilitated the implementation of interdisciplinary projects, enabling both faculty and students to analyse content and competencies from multiple courses within a single instructional plan. By allowing participants to visualize how different courses contribute to a larger project, the canvas strengthens curricular integration and promotes a more holistic view of the learning experience.

Based on these findings, we recommend the adoption and expansion of the planning scenarios presented in this study, as presented in the Figure 2.

In addition, we suggest the periodic reapplication of the flowchart presents in Figure 2 to reinforce alignment and promote continuous improvement.

The proposed scenarios are as follows: **Scenario 1:** Professors from different courses collaborating to create shared interdisciplinary projects within the same academic term. **Scenario 2:** Professors teaching the same course across different degree programs. **Scenario 3:** Professors within the same program who teach courses aligned with a common knowledge area or disciplinary track.

The results highlight the functionality of the canvas as a planning tool and its potential as an institutional catalyst for the adoption of active learning methodologies. The clear visualization of course components and the integration of competencies, methods, and assessments make the canvas a concrete bridge between planning and classroom implementation—an element often missing in pedagogical innovation initiatives. This research contributes to the field by proposing a replicable and adaptable model for different educational contexts.

5 Conclusion

The findings of this study demonstrate that collaborative and integrated planning, supported by the canvas proposed herein, is an effective strategy for promoting curriculum integration and enhancing the quality of instructional design. The transition from a physical to a digital canvas platform proved advantageous, expanding the reach and depth of collaboration among instructors. This shift resulted in greater cohesion and alignment of course content and the pedagogical methodologies applied.

Moreover, the integration of active learning methodologies and digital technologies played a key role in increasing student engagement, as evidenced by the positive evaluations gathered throughout the study.

Future research should further investigate the impact of this planning approach in diverse disciplinary contexts. In addition, studies should explore the effectiveness of other collaborative digital tools and focus on developing more robust strategies for faculty development in the use of active learning methodologies and technology-supported instructional planning.

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Engineering and Social Impact: Student Perceptions of Competencies for Social Entrepreneurship

Afsaneh Hamedí d'Escoffier¹, Luiz Ney d'Escoffier¹, Frederico Pifano de Rezende^{2,3}

¹ Laboratório de Protozoologia, Instituto Oswaldo Cruz, Fiocruz, Rio de Janeiro, Brasil

² Texas A&M University, Texas, USA

³ Instituto Federal do Espírito Santo, Espírito Santo, Brasil

Email: afsanehamedí@gmail.com; lescof@ioc.fiocruz.br; fredpifano@gmail.com

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Abstract

This study aims to deepen the understanding of engineering students' perspectives on the competencies required for social entrepreneurship. While entrepreneurship drives development through innovation and economic growth, social entrepreneurship goes further by balancing social impact and financial sustainability. Social entrepreneurs operate in for-profit, non-profit, or hybrid organizations, requiring personal, business, and managerial competencies. In addition to traditional skills like innovation and risk-taking, virtues, collaboration, and empathy are essential. Although universities have invested in entrepreneurial education, research on social entrepreneurship remains limited, gaining prominence only in the past decade. Our study seeks to understand engineering students' perceptions of these competencies through a qualitative approach, using thematic analysis of open-ended responses. The study involved 48 engineering students from Texas A&M University, USA. Preliminary results indicate a multidimensional perspective, emphasizing resilience and risk-taking—competencies associated with traditional entrepreneurship. Business success emerged as the primary concern, with adaptability and courage considered essential. In contrast, social aspects were deemed less important, with social awareness—a core competency of social entrepreneurship—ranked as insignificant. Justifications reflect a belief that success depends on individual talent and that inclusion is not essential for a company. This suggests that students view entrepreneurship solely through a profit-driven lens, disregarding its social impact. To broaden the analysis, we will apply the same methodology to students at the University of Brasília, Brazil, who experience a different reality and lack formal entrepreneurship courses in engineering. By comparing these perspectives, we aim to outline the role of universities in shaping engineers' competencies for social entrepreneurship and explore connections between curriculum design and competency development. Ultimately, we hope to contribute to discussions on how engineering education can foster skills geared toward social development.

Keywords: Entrepreneurship, competence, sustainability, undergraduate.

1 Introduction

Addressing social challenges such as housing, healthcare, and education for marginalized communities requires innovative approaches beyond governmental and traditional business solutions. Social entrepreneurship has emerged as a response to these unmet needs, gaining recognition in the 1980s and 1990s through the contributions of Bill Drayton and Charles Leadbeater (Dornelas, 2001), despite entrepreneurship itself being rooted in economic theory since Schumpeter (1911).

At its core, social entrepreneurship involves identifying and leveraging opportunities to generate social value. While Certo and Miller (Certo & Miller, 2008) define it as a structured process of opportunity recognition, Steinerowski and cols. (Steinerowski, Jack & Farmer, 2008; Dacin, Dacin & Matear, 2010; Nga & Shamuganathan, 2010) emphasize its financial sustainability model, where profits are reinvested to enhance social impact. Lubberink (Lubberink, 2019) further highlights the ability of social entrepreneurs to pinpoint systemic failures and develop innovative, yet often complex, solutions that require effective management strategies.

Entrepreneurial competencies are essential for tackling social issues and advancing the Sustainable Development Goals (SDGs) (UN, 2015). McClelland (McClelland, 1973) conceptualizes competence as a combination of knowledge, skills, and attitudes, while Brinkmann (Brinkmann, 2007) expands this notion to encompass social, technical, and psychological attributes. In social entrepreneurship, competencies such as social innovation, leadership, strategic management, empathy, sustainability orientation, and emotional intelligence play a decisive role in success (Vázquez-Parra, García-González & Ramírez-Montoya, 2021).

Despite growing recognition of the need for education in social entrepreneurship, there remains a lack of standardized curricula and pedagogical strategies to effectively develop these competencies (Pittaway & Cope, 2007; Alourhzal & Hattabou, 2021). Research indicates that students often perceive deficiencies in their training, particularly concerning social innovation and business management (Cruz-Sandoval, Vázquez-Parra & Alonso-Galicia, 2022).

This study is part of a broader research project that employs Q methodology. Contribute to the field by examining which entrepreneurial competencies are most valued by students and educators in engineering education, applying Q methodology in two distinct educational contexts (Stephenson, 1935; Watts & Stenner, 2012). While Q methodology has been employed in general entrepreneurship research, its application in social entrepreneurship remains underexplored (Qureshi, Bhatt & Riaz, 2012; Bhatt, Qureshi & Riaz, 2019). By addressing this gap, the study aims to inform the design of educational strategies that foster key skills and values essential for social entrepreneurship, ultimately promoting sustainable development.

2 Methodology

2.1 Research context and participants

The data collection took place over two consecutive semesters at Texas A&M University (TAMU) in the course *Enterprise Basics for Technical Entrepreneurs*. This is an elective course offered by the Department of Multidisciplinary Engineering through the *Meloy Program in Engineering, Innovation, and Entrepreneurship*, which aims to foster an entrepreneurial perspective among engineering students.

The group of 68 students who responded voluntarily to the questionnaire came from at least 10 different engineering programs out of the 26 offered at TAMU. The course is offered regularly each semester and, since it has no prerequisites, it is open to both undergraduate and graduate students.

Most of these students have only a technical engineering background, with little or no prior knowledge of entrepreneurship. The course's primary goal is to introduce students to business-related content and encourage an entrepreneurial mindset. There is no specific research on this, but the actual intention to start a business is estimated to be below 10% at the beginning of the semester. The data was collected within the first month of the course.

2.2 Research design

As part of a larger study, participants were asked to rank a series of statements related to social entrepreneurship competencies, organizing them from most to least important. The study primarily employs Q methodology as its research design (for more details on Q methodology, visit: <https://qmethod.org/>). Additionally, it incorporates open-ended questions, allowing students to elaborate on their reasoning for prioritizing certain competencies over others and to suggest additional competencies they believe should be integrated into their education.

The qualitative data, collected from 48 students, underwent manual thematic analysis using an inductive approach. Responses were categorized based on the competencies they referenced, while the justifications provided were examined to identify underlying reasoning patterns and assess the coherence between the selected competency and the accompanying explanation. This analysis was then used to construct a qualitative profile of the student groups, offering insights into their perceptions of the engineer's role in social entrepreneurship.

3 Results

The results indicate that students most valued the competencies of risk-taking and resilience, both linked to traditional entrepreneurship. Although other competencies were mentioned, their relevance was not statistically significant. Notably, 81% of students prioritized traditional entrepreneurship competencies, showing a strong preference for business creation and growth focused on economic value.

Conversely, 69% of students devalued competencies related to social entrepreneurship, with social awareness most frequently cited as less important. This highlights a market-oriented mindset, with little emphasis on generating positive social impact.

These findings suggest that engineering students tend to favor competitiveness and financial sustainability over social innovation and sustainable development. This likely reflects the traditional focus of engineering curricula on technical efficiency and economic viability, shaping how students perceive their professional role in society.

The following sections analyze students' justifications for their choices, offering deeper insights into their views on entrepreneurship's impact on their careers.

3.1 Risk-taking

This competency was rated as the most relevant by students, reflecting an orientation aligned with traditional entrepreneurship. Its importance is associated with business growth and success, facilitating entry into new markets, the development of innovative products, and the ability to strategically face competition. The emphasis placed by students suggests a predominantly business creation and expansion-oriented perspective, prioritizing the maximization of opportunities and economic sustainability.

This result indicates a strong appreciation for competitive strategies and innovation as essential elements for business success. In the context of traditional entrepreneurship, the pursuit of market differentiation and operational efficiency are key factors for business longevity. Thus, the prioritization of this competency by students reflects an understanding of market dynamics and the need for continuous adaptation to ensure a competitive advantage.

The justifications provided reinforce this perspective, highlighting the concern for business success from a strategic, market-oriented approach, as demonstrated in the following information:

"The whole essence of entrepreneurship is in my opinion learning and creating opportunity. By being willing to fail, you can maximize validated learning."

"Having the courage to fail or being risk tolerant allows entrepreneurs to try novel ideas. Without risk, there is very little that would set entrepreneurs apart."

"Entrepreneurs must be perseverant and willing the failure before filing their success. Without this, all others would not matter because they will turn away at the first sign of trouble".

3.2 Resilience

The second competency highlighted by students was resilience, also linked to traditional entrepreneurship. This competency can be defined as the ability to face daily challenges, overcome obstacles, and maintain adaptability in the face of adversity, being especially crucial in the early years of a company—a period characterized by greater instability and uncertainty.

Resilience plays a fundamental role in business sustainability, allowing entrepreneurs to learn from failures, adjust strategies, and remain operational even in the face of financial, structural, or market difficulties. The ability to recover and adapt not only mitigates the impact of crises but also strengthens the company's competitive position in the long term.

The justifications provided by students reinforce this perspective, emphasizing that the ability to handle and learn from mistakes is essential for business success, as demonstrated below:

"Every entrepreneur will fail at some point, it is how they handle those failures that determine whether or not the company will become successful"

"An entrepreneur needs to be able to handle risks of unforeseen changes as they will come no matter what"

"The ability to adapt to change is the feature that separate it from operation. Entrepreneurship is inherently an uncertain endeavor. Without grit, one is set to fail any entrepreneurial undertaking"

3.3 Social awareness

When analyzing the competencies rated as least important by students, it becomes evident that social awareness was the most frequently devalued. This competency is strongly associated with social entrepreneurship, as it involves the ability to recognize social and environmental challenges and proactively work toward sustainable solutions. However, the justifications provided indicate that students do not consider it essential for business success, particularly regarding social inclusion.

The students' statements reflect a pragmatic view of entrepreneurship, prioritizing aspects that directly impact business growth and competitiveness. Social inclusion is perceived as secondary or even irrelevant to idea generation and business expansion. The following justifications illustrate this perspective:

"Inclusion is not particularly important, talent + skill is."

"Although inclusion is important both ethically and morally and can sometimes be useful to the company, it does not directly lead to better company growth, idea generation, or an innovative mindset as well as the other items."

These statements reveal a mindset strongly focused on financial performance and innovation, to the detriment of ethical and social values. Business success is positioned as the absolute priority, surpassing considerations of social impact or corporate responsibility. This result suggests that, for these students, entrepreneurship should be primarily guided by economic metrics, relegating social awareness to a peripheral or even dispensable role in the business context.

4 Discussion

The results highlight a misalignment between the competencies valued by engineering students and those essential for social entrepreneurship. While traditional competencies like resilience and risk-taking were prioritized, students gave little importance to social awareness, empathy, and systemic vision, reflecting a predominantly market-oriented view of entrepreneurship based on individual talent and financial success.

This tendency is linked to the structure of engineering curricula, which emphasize technical efficiency and economic viability, limiting students' understanding of engineering's role in addressing social challenges. The literature confirms that engineering education often underestimates the importance of hybrid business models that balance profit and social impact.

To address this, a holistic curricular approach is needed, one that combines management tools with values like social responsibility and sustainability. Active learning methods such as PBL and PjBL can foster a mindset more oriented toward social problem-solving, but their effectiveness depends on the intentional integration of social themes, including equity, inclusion, and sustainability.

Interdisciplinary modules involving social sciences, economics, and impact management can enhance students' preparedness for complex social entrepreneurship contexts. The planned research expansion to the University of Brasília (UnB), where no formal entrepreneurship courses exist in engineering, will allow comparison between educational realities and inform strategies for better competency integration.

These findings reinforce the urgency of curriculum reforms that embed social entrepreneurship as a core component of engineering education. Frameworks like CDIO and UNESCO's Engineering for Sustainable Development provide pathways to align curricula with the Sustainable Development Goals (SDGs). Additionally, mandatory interdisciplinary projects and revised learning outcomes, guided by models like EntreComp, can support the development of empathy, systemic thinking, and ethical reasoning.

Such reforms should be accompanied by faculty development, equipping educators to address ethical and social justice issues. Without structural changes, even active methodologies risk reproducing traditional technical approaches under new formats.

In sum, this study advocates a systemic redesign of engineering curricula to make social entrepreneurship integral to professional identity. Expanding the research to the Brazilian context will deepen the debate on preparing engineers to contribute ethically and effectively to social transformation, making a positive impact a central educational commitment rather than an optional goal.

5 Conclusion

This study reveals a significant gap between the competencies valued by engineering students—such as resilience and risk-taking—and those essential for social entrepreneurship, like social awareness and inclusion. Students tend to associate entrepreneurship with financial success and individual ability, reflecting the traditional engineering education focus on technical efficiency and economic viability, and overlooking its social dimension.

Bridging this gap requires rethinking how social entrepreneurship is taught. Active learning methods like PBL and PjBL, along with interdisciplinary approaches that include social sciences, economics, and sustainability, can help students develop a more holistic understanding of entrepreneurship as a driver of social change.

The planned expansion of this research to students at the University of Brasília (UnB)—where formal entrepreneurship training is lacking—will offer comparative insights into how curricular design influences perceptions and preparedness for social entrepreneurship.

Ultimately, universities play a key role in shaping future engineers. By integrating social responsibility into entrepreneurial education, institutions can better equip students to foster sustainable development, promoting a multidimensional view of entrepreneurship that balances economic, social, and environmental goals.

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Teacher Training in Hybrid Learning Environments: Artificial Intelligence, Ethics and Socioemotional Aspects in the Digital Material Production Course

Andromeda Goretti de Menezes Campos¹, Talita Molina Lopes Tanes¹

¹ Federal Institute of Education, Science and Technology of Espírito Santo, Brazil

Email: andromeda.campos@ifes.edu.br, talitatanes@gmail.com

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Abstract

This paper discusses the development of the Digital Material Production course for educators, conducted in the first semester of 2025. In this iteration, the project "Potentialities of Generative Artificial Intelligence (AI) in Education" served as its backbone, differentiating it from previous editions. With a central theme that was both comprehensive and engaging, the course aimed to equip students with knowledge about the use of AI in education, explore generative AI tools for digital material production, understand the ethical and responsible use of these technologies, and foster greater engagement in both in-person and remote settings. The project was structured into three stages: (1) an introduction to learning theories and instructional design models; (2) hands-on production of digital educational materials using AI tools; and (3) a final seminar where students presented their outputs and participated in discussions on AI ethics, copyright, and social inclusion. A comparative analysis of the educational materials produced indicated a qualitative improvement, with students demonstrating a deeper understanding of AI ethics. Furthermore, the number of students attending more than 60% of in-person classes increased by 13.33% compared to the previous cohort, suggesting a higher level of engagement fostered by the hybrid model. However, participation in the Virtual Learning Environment (VLE) was lower than expected. This could be attributed to factors such as difficulties with digital literacy, a common challenge in online learning environments. This experience reinforces the transformative potential of AI in education, provided that it is balanced with ethical awareness and socioemotional competencies. The findings highlight the need for adaptive pedagogical strategies that effectively integrate AI, ensuring inclusivity and promoting the reflective and responsible use of technology in teaching and learning processes.

Keywords: Socioemotional; AI; Ethics; Teacher Training.

1 Introduction

The transformations brought about by digital technologies in education have intensified with the expansion of Artificial Intelligence (AI), particularly generative AI. Tools such as ChatGPT, DALL-E, Perplexity, and other multimodal interfaces have directly impacted school routines, from content production to learning mediation. These advances challenge educators and institutions to reconfigure not only their pedagogical practices but also their conceptions of the teaching role, knowledge, and learning itself (Luckin et al., 2016; Holmes et al., 2019; Huang et al., 2023).

Despite the promises of personalization, automation, and increased efficiency in education promoted by AI (Zhao et al., 2022), studies show that its implementation in educational settings requires ethical, epistemological, and pedagogical care. Uncritical adoption of technologies may reinforce social inequalities, deepen human detachment in educational processes, and compromise fundamental educational principles such as equity, authorship, and the holistic development of learners (Borenstein & Howard, 2021; Amaral et al., 2022; Moura et al., 2022).

In this context, teacher education emerges as a central axis. Teachers need not only to understand how AI tools operate but also to develop a critical and ethical stance toward the social, political, and emotional impacts of this technology in educational contexts (Becker & Marques, 2001; Franco et al., 2006; Silva et al., 2022). Some

studies highlight that many educators still feel unprepared to face these challenges, mainly due to a lack of continuing education that integrates theory, practice, and ethical reflection (Holmes et al., 2019; Franco et al., 2006; Amaral et al., 2022).

The ethics of AI use in education, in turn, has been extensively discussed in the scientific literature. Issues related to algorithmic transparency, data privacy, intellectual property, and systemic biases embedded in AI-trained datasets are identified as central to the responsible implementation of these technologies (Borenstein & Howard, 2021; Amaral et al., 2022). Furthermore, the emergence of increasingly autonomous systems, capable of making decisions based on opaque criteria, raises concerns about the dehumanization of pedagogical relationships and the marginalization of dissenting voices (Huang et al., 2023; Holmes et al., 2019).

Alongside technical and ethical debates, another field has gained prominence: affectivity and the socio-emotional aspects of technology-mediated education. According to Henri Wallon (1968) and Jean Piaget (2014), affectivity is an essential component of the teaching-learning process, as it mobilizes students' motivation, will, interest, and engagement. When neglected, especially in remote or hybrid contexts, it can undermine the bond between teacher and student, increase feelings of loneliness, and promote dropout (Blando et al., 2023; Vieira et al., 2022; Trierweiler, 2024).

Case studies reveal that often invisible affective difficulties directly impact students' academic performance and their sense of belonging within the university environment. Factors such as insecurity, lack of motivation, insufficient institutional support, and distant teacher-student relationships are identified as barriers to meaningful learning (Silva et al., 2022; Blando et al., 2023; Jacques et al., 2015). These findings highlight the need for teacher education to also include the development of socio-emotional skills, such as empathy, active listening, emotional support, and conflict mediation.

In the case of Distance Education (DE), these demands become even more urgent. Brazilian literature on DE indicates that, despite technological advancements, many programs still maintain an instructionist logic focused on content transmission, disregarding dialogical mediation and student care (Franco et al., 2006; Kieling Franco et al., 2006). Research shows that affectivity in DE is directly related to academic success, student retention, and the quality of the educational experience (Marcilio et al., 2023; Vieira et al., 2022; Moura et al., 2022).

Still within this context, Villas-Boas (2019) argues that there is a rupture of previously consolidated concepts and models, requiring teachers to confront new challenges and complex dilemmas. In this scenario, educators seek to develop strategies to present knowledge meaningfully in the classroom, considering that students access information through the internet in various contexts; they promote initiatives to stimulate reading and efficient study practices, even in an environment characterized by the constant presence of digital media; and they strive to integrate knowledge and skills development with the technologies available, aiming to foster lasting learning.

Thus, there is a need for the training of education professionals who are practically familiar with Active Learning (AL) strategies and methods, as they support students' active engagement in their learning processes, reduce dropout and retention rates, stimulate greater student autonomy, create learning environments where students are required to use higher-order thinking skills (analyze, synthesize, create (ANDERSON et al., 2001)), and contribute to the development of more creative teachers.

Given these challenges, this article aims to present and analyze the formative experience, that is, a structured and intentional educational approach aimed at fostering critical thinking, ethical awareness, and socioemotional development, offered through the course Production of Digital Materials, conducted in the first semester of 2025, as part of the Technical Program in Educational Multimedia, offered through distance

learning with mandatory in-person meetings, at the Federal Institute of Espírito Santo. Unlike previous editions, this version was structured based on active learning, with the central theme "Potentialities of Generative AI in Education," integrating the following areas: theoretical foundations of learning, active learning for the production of digital educational materials (DEM) with and without AI, and ethical and socio-emotional discussions on its educational application. The course was designed not only to develop technical skills but also to foster an ethical, reflective, and affective attitude in the use of technologies and in the interpersonal relationships involved in the teaching and learning process, contributing to a more integrated teacher education aligned with contemporary challenges.

2 Research Design

This section describes the methodological choices adopted for the development of the study, considering the justifications that motivated its implementation and its contributions based on the results obtained.

The research presented is descriptive in nature, as it is based on the researchers' prior knowledge of the investigated issue. A qualitative-quantitative methodological approach was adopted, integrating quantitative and qualitative aspects in a complementary manner. The quantitative dimension is reflected in the analysis of numerical data, which allows the measurement of results and the identification of objective patterns. The qualitative dimension, on the other hand, is essential for gaining a deeper understanding of the perceptions and experiences of the individuals directly involved in the studied context, enabling a more sensitive and contextualized interpretation of the investigated reality.

The main data collection techniques adopted in this study were observation, questionnaires, and document analysis. Non-structured observation was chosen, prioritizing a spontaneous and natural approach, which allowed for more authentic immersion in the investigated environment. To systematically record these observations, a field diary was used to document students' behaviors, reactions, and attitudes individually, aiming to contribute to the validation of the initial hypothesis. Observation, in this sense, proves to be a valuable tool for capturing aspects of reality that cannot be apprehended solely through questionnaires or documents, as it enables the analysis of phenomena in their concreteness, at the time and place in which they occur (Deslandes, 2007).

The questionnaire was used because, according to Gil (2010), as a data collection instrument, it offers significant advantages, such as ensuring the anonymity of responses, providing respondents with the flexibility to participate at a convenient time, and reducing the influence of interpersonal factors, such as the researcher's presence or the interviewee's characteristics. In this study, the questionnaire aimed to capture students' perceptions regarding the transversal use of affectivity in the teaching and learning process, as well as their perceptions of the effectiveness of the methodology applied.

Document analysis was necessary because, throughout the course offering, attendance at in-person sessions was recorded, access to Moodle and to each element within the Virtual Learning Environment (VLE) was logged (by student), and problem-solving activities were posted, analyzed, resolved, and evaluated, generating documents containing students' grades and responses. Stake (1995) attributes a complementary role to document analysis relative to other sources of evidence, highlighting its relevance especially in contexts where direct observation is not possible. According to the author, documents can provide valuable information that contributes to understanding the investigated phenomenon, serving, in some cases, as substitutes for experiences not directly witnessed by the researchers.

Finally, the results were analyzed from the perspectives of both the students and the instructors and are discussed in the following sections of this paper.

3 Course Methodology (ADDIE + Active Learning + Socio-emotional axis)

According to Gava, Nobre, and Sondermann (2014), the planning and implementation of courses across various programs must be carried out in an integrated manner and contextualized to students' everyday experiences. Particularly in Distance Education (DE), such planning must be highly detailed, especially when utilizing a Virtual Learning Environment (VLE).

For the development of the Production of Digital Materials course, the ADDIE Model was employed, as it is a widely used instructional design methodology that aligns with the institution's specificities. In the specific case of this course's production, the authors possessed the necessary expertise and assumed the following roles: Instructor 1 served as the instructional designer, content specialist, teacher educator, and online tutor; Instructor 2 served as the instructional designer, pedagogical specialist, and text editor. Figure 1 presents the ADDIE Model, its phases, and the description of the actions undertaken in each phase.

ADDIE Model			
	Phase	Question	Actions
Concep- tion	Analysis	Understand the task to be performed	Define: • Target audience • Learning context • Learning goals Consider: • Resources • Infrastructure • Deadlines
	Design	Structuring the Material	Define: • Learning objectives • Media to be used • Evaluation methods
	Development	Producing the Material	Produce: • Designed materials
Executi- on	Implementation	Validating the Material	Perform: • Validation tests • Implementation of the material
	Evaluation	Evaluating the Material	Evaluation • Ongoing, throughout the project • Final, with the material users miro

Figure 1. ADDIE Model. Adapted from Gava, Nobre, and Sondermann (2014).

Based on the proposal presented by Gava, Nobre, and Sondermann (2014), the ADDIE Model can be structured into two main blocks: Design and Implementation. This organization aims to systematize the stages involved in the development of educational materials, contributing to coherence between pedagogical objectives, methodologies, and the resources adopted.

Drawing on the data gathered during the analysis phase, a pedagogical plan was developed for the course content, including the systematic definition of learning objectives, the organization of content and activities, and the design of assessment methods. In addition, the media and technologies most appropriate to the identified context were selected, ensuring coherence among educational elements and enhancing the effectiveness of the teaching and learning process. The course methodology for Production of Digital Materials was thus defined for implementation in the first semester of 2025. Subsequently, in line with the ADDIE framework, the educational materials were developed according to the previously established plan.

To design the methodology to be applied in the course, the team evaluated recurring issues observed in previous editions, such as student failures, low participation in face-to-face sessions, and limited engagement in the virtual learning environment. This was coupled with students' concerns—many of whom are practicing educators—regarding the operation of AI tools and the need for a critical and ethical stance on the social, political, and emotional impacts of such technologies in education. Another important factor was the need to

prepare education professionals to design digital educational materials and to develop competencies for working with active learning methodologies in hybrid learning environments.

3.1 Theoretical Content Development: Production of Digital Materials

With regard to the theoretical content—or content that was not part of the active methodology proposed in this study—the course included the following topics: Educational Resource Development, Media for Distance Education, Digital Educational Materials (DEMs), and a reflection on their implications for education.

Students also explored Learning Theories and Learning Styles with the aim of providing a theoretical foundation for the development of Digital Educational Materials. In addition, they engaged with, in order to assimilate and apply, the potential of Virtual Reality (VR) and Augmented Reality (AR) in education.

Assessments for these topics were conducted online, asynchronously, and individually—differently from the problem-based learning (PBL) tasks. For the theoretical content, traditional questionnaires were used. However, when assessing the “problem situations,” the application of concepts was evaluated in practice, based on pre-established criteria using rubrics.

3.2 Development of the Active Methodology for the Course “Production of Digital Materials”

Problem-based learning (PBL) scenarios were used as the active methodology, with components developed both in-person and remotely. The choice of this format aimed to enhance students’ sense of belonging to the institution, as teamwork fosters relationships among students and between students and the instructor. Active learning also promotes autonomy, stimulates critical thinking, strengthens problem-solving skills, values collaborative work, and enhances students’ adaptability—preparing them to face real-life challenges.

The PBL scenarios explored by the 17 students enrolled in this course were structured as follows:

- **Central Theme:** The Potential of Generative Artificial Intelligence in Education.
- **Subthemes:** Intelligent Tutoring Systems; Educational Chatbots; Personalized Learning; Artificial Intelligence and Inclusion in Education; Ethics and Artificial Intelligence in Education; and Artificial Intelligence in Early Childhood Education.
- **Team Size:** Maximum of 5 students.
- **Target Audience:** Defined according to each scenario.
- **Resolution Time:** 1 to 2 weeks (depending on complexity).
- **Number of PBL Scenarios:** 5.
- **Educational Materials Developed:** Infographic, Animation, Podcast, Video Lesson, and Recorded Slide Presentation.

For the development of the problem scenarios, the authors used ChatGPT, following the construction of a specific prompt designed for this purpose. An example of a problem scenario explored in the “Production of Digital Materials” course is presented below:

Problem-Based Scenario:

You have been invited to develop a Digital Educational Material for 2nd-year high school students at a private school located in an urban area in Brazil. The school adopts active learning methodologies and is currently carrying out an interdisciplinary project on “Ethics and Artificial Intelligence in Education.”

Target Audience Characteristics:

- *Students aged 16 to 17, with strong proficiency in digital technologies (frequent use of smartphones, social media, online educational platforms, and research tools).*
- *They have a basic familiarity with the concept of Artificial Intelligence but only an initial understanding of its ethical implications.*
- *They show high potential for engaging in debate and reflective activities but require visual stimuli, hands-on activities, and interactive resources to stay engaged.*
- *The school values the inclusion of diverse perspectives and the development of students' intellectual autonomy.*

Specific Needs:

- *Present the topic in a thought-provoking, critical, and accessible way.*
- *Stimulate critical thinking and ethical argumentation.*
- *Use media resources that encourage active student participation.*

Your Task:

- *Use the provided templates to document and plan the production of your Digital Educational Material.*
- *Plan your material based on the ADDIE Model and develop a Digital Educational Material that introduces and deepens the theme "Ethics and Artificial Intelligence in Education." It should promote reflection on issues such as data privacy, algorithmic bias, system transparency, and the ethical responsibility of AI developers and users.*
- *Choose appropriate technologies and media, suited to the students' profile, to create an engaging and participatory learning resource.*
- *You may use Artificial Intelligence tools to support material development (e.g., AI for image generation, video editing, or generating debate questions). If used, you must clearly identify which tools were used, at what stage, and reflect on the ethical implications of their use.*

By the end, you should be able to describe:

- *The material developed (type of media, technologies used, format).*
- *How the needs of the target audience were considered in choosing the language, media, and activities.*
- *A critical reflection on the use of Artificial Intelligence in the creation process and on the ethical approach proposed in the content.*

Figure 2 illustrates the dynamics of applying problem-situations in this course. Since the problem-situations are linked to a central theme rather than to different topics, students were able to focus on a single context. This allowed them to explore the development of various Digital Educational Materials, using distinct media formats (audio, image, video, text, etc.) and diverse digital technologies, enabling them to compare the potential of each and assess their suitability for different pedagogical objectives and target audiences — all within the same theme.

Initially, during the first in-person class, teams were formed directly within the Moodle Virtual Learning Environment (VLE), and each group selected a subtheme. In a second stage, in another class, the first problem-situation was presented, and students, based on their prior knowledge and the knowledge acquired in the course, had to develop a functional solution. This development was to be carried out by applying the ADDIE Model, but adapted specifically for the production of a digital educational material, no longer in the broader scope of an entire course or subject. After the submission of the first solution, a new problem-situation was presented.

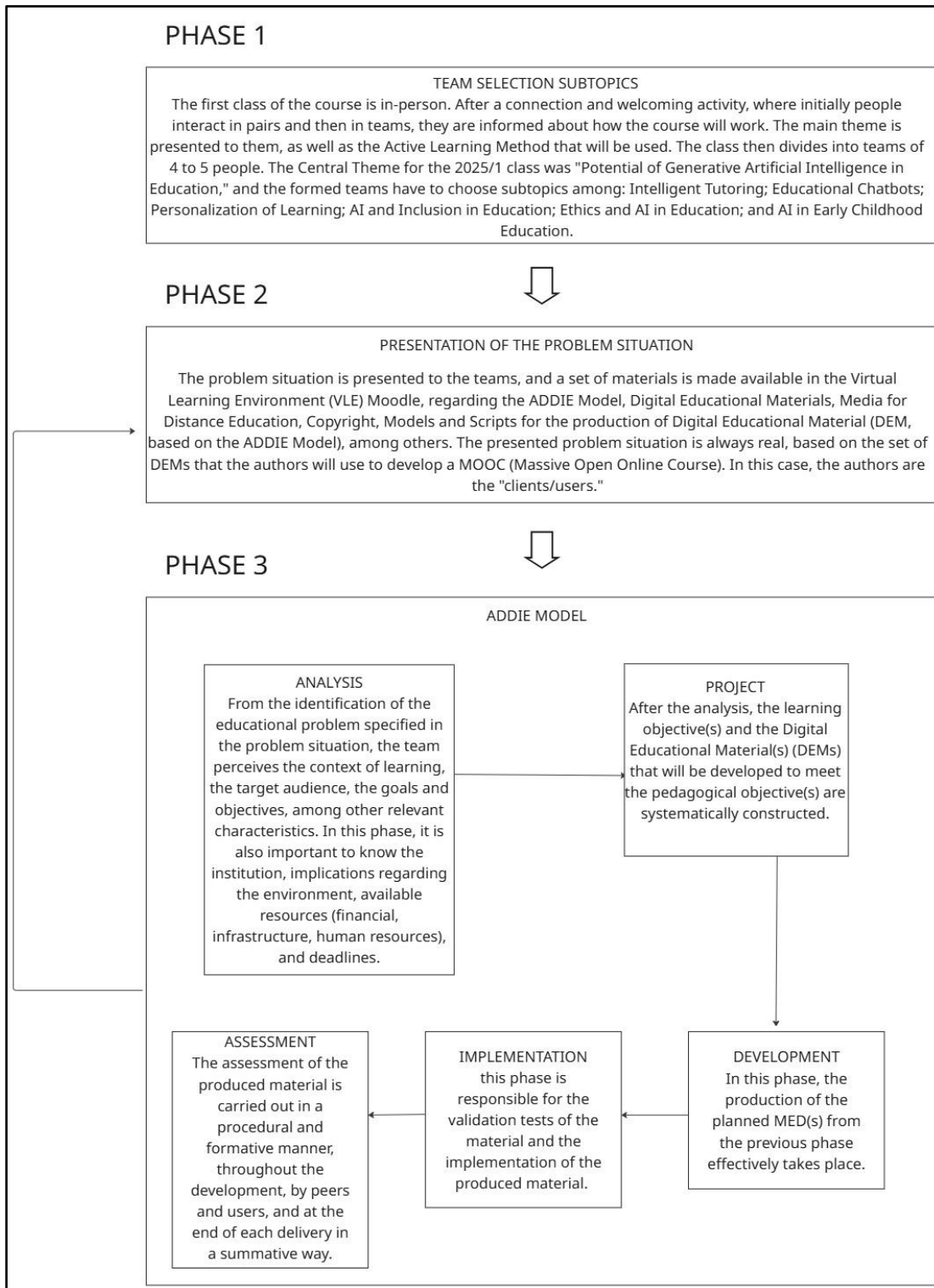


Figure 2. Active Methodology used in the Digital Material Production course in 2025/1. The authors (2025)

3.3 Integration of Ethical and Socioemotional Transversal Competencies

Based on research cited in this article, several authors indicate that affectivity in Distance Education (DE) is directly related to academic success, student retention, and the overall quality of the educational experience. Despite technological advancements, many courses still adhere to an instructional logic centered on content transmission, neglecting dialogic mediation and student care.

When one of the authors took over the course in the first semester of 2024, a diagnostic assessment was conducted with the group, revealing a class of discontented students who resisted teamwork, complained about having to attend in-person classes, the volume of required readings, the number of assignments, the lack of time, limited familiarity with educational technologies, and a perceived lack of empathy from various stakeholders in the program, among other concerns.

After assessing the course structure, already developed within the Moodle VLE, and considering the limited time available, it was clear that a complete structural reform would not be possible. Instead, specific changes were implemented, particularly in the approach to working with the students and during the in-person sessions, which accounted for 20 hours of the total 90-hour course load. The students' progress during the 2024/1 offering was monitored, focusing on the aspects developed with the group. In subsequent offerings, through a continuous improvement process, the results culminated in the work presented here.

Thus, with a total workload of 90 hours, the course was fully developed within Moodle, aiming to ensure that graduates understand current digital technologies and their role in education, as well as the potential and systematic production of digital educational materials. The objective was to utilize both established and innovative technological resources effectively and ethically, fostering an affective and responsible approach to digital resource development.

4 Results and Discussion

In this section, the results of this work will be presented, compared to previous course offerings, along with findings from a questionnaire applied and analyzed to understand students' perspectives regarding the development of the most recent offering of the course. Below is a list of methodological changes, comparing the evolution between the first and the third offerings taught by the professor:

2024/1:

- Single theme for the production of Digital Educational Materials (DEMs), but without the structured case-scenarios. Students were responsible for choosing their target audience and did not follow a specific script.
- Traditional learning modality.
- DEMs are produced entirely online in teams.
- Responses to questions exceeding a 24-hour delay.
- Assignment corrections taking more than one week after submission.
- General feedback provided, focused on guiding students toward knowledge acquisition.
- Weekly messages and reminders sent on the eve of assignment deadlines.
- In-person classes focused only on theoretical content.
- Use of tools already familiar to students for supporting the production of digital materials.

2025/1:

- Single theme for DEM production based on specific case-scenarios.
- Use of Active Learning methodologies.
- DEM production was initiated during in-person classes and continued online in a collaborative learning environment.
- Responses to student questions provided within 24 hours.
- Assignment corrections completed within a maximum of one week after submission.

- Individualized feedback on assignments, prioritizing reinforcement of what the student did correctly, suggestions for improvement, and only afterward pointing out mistakes with guidance on how to address them.
- Weekly emails and posts in the "News Forum" providing clear, personalized instructions regarding weekly activities, along with reminders before deadlines. Messages became more personalized, using Moodle resources and a more humanized, affective writing style.
- In-person classes redesigned to incorporate welcoming activities and creativity, with and without the use of technologies.
- Teaching and application of Artificial Intelligence tools to support the planning and development of DEMs, with emphasis on ethical considerations and the importance of learning how to use AI responsibly.

The graph below illustrates the evolution of student engagement in face-to-face classes, comparing the offerings from 2024/1, 2024/2, and 2025/1. A significant increase in student involvement is observed, especially after the implementation of active learning methodologies and the introduction of affective and humanized practices both in face-to-face classes and in the virtual environment. This increase in engagement can be attributed to content personalization, the use of innovative technologies such as Artificial Intelligence (AI), and a more welcoming and attentive approach to meeting the students' needs.

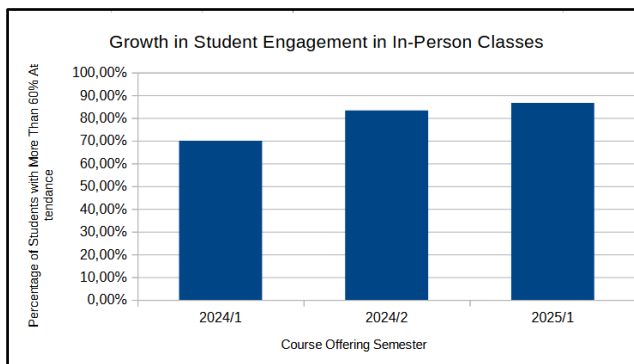


Figure 3 - Graph of Student Engagement Growth in In-Person Classes.

The first class included a moment called "Welcoming and Connection," aimed at breaking the ice in a situation where the students did not know the professor, and vice versa. This type of activity was conducted in other face-to-face classes, in smaller proportions, with different approaches, always encouraging speaking, listening, creativity, and progressively increasing the students' sense of belonging to the institution.

Affective and empathetic interactions brought the class closer together, improved the teacher-student relationship, and reduced emotional distance. In addition to constant student feedback regarding the classes and their management, a questionnaire was applied at the end of the course. Out of the 17 students, 13 responded. Some of the results are described below:

Regarding the perception of the teacher's welcoming attitude, listening, empathy, and care throughout the course, 100% of respondents stated that it was very present; 84.6% affirmed that they felt completely motivated to participate in the face-to-face classes due to the affectionate atmosphere proposed by the course; 100% of respondents stated that the affective nature of the interactions (messages, feedbacks, mediations, etc.) contributed to their increased engagement in activities in the Moodle Learning Management System (LMS); when compared to other courses in the same program, 84.6% felt a distinctive care and attention to their feelings and needs, while 15.4% felt it was the same as in other courses.

Below are some student responses to open-ended questions about the affectivity in the course:

P1: Did the affective aspect of the course contribute to your perseverance and participation throughout the course? If so, how?

- **Student 1:** Yes, the affective aspect of the course contributed greatly to my perseverance and participation. The way the professor conducted the classes, always with empathy, patience, and openness to listen, made me feel more comfortable participating and learning. This created a light and welcoming environment where I felt motivated to continue, even when difficulties arose.
- **Student 2:** Yes. The professor was able to involve the class in such a way that it even brought the students closer together.
- **Student 3:** In the weekly messages and feedback on activities.
- **Student 4:** Yes, teamwork.

P2: Leave a comment about how you felt regarding the care, empathy, and welcoming during the course. Did this make any difference in your learning experience?

Student 1: The course is very inclusive, and the professor understands the specificities of each student, valuing each individual's unique aspect and ensuring greater motivation in the classroom.

Student 2: During the course, I felt very special care from the professor, with a lot of empathy and welcoming. This made all the difference in my learning experience, as I felt respected, heard, and motivated to participate. Knowing I could count on a safe and non-judgmental environment gave me more confidence to express myself, ask questions, and truly engage in the activities.

Student 3: I felt motivated and happy. I always believed in my potential, and the professor did as well.

Student 4: It helped a lot, especially with my study routine. Even though I couldn't attend all the face-to-face classes, I never felt distant from the professor and the class.

Based on the questionnaire applied to the students, 85% stated that the central theme of the course was either highly or very motivating and challenging, while 15% rated it as moderately motivating. Regarding the skills developed through the active learning methodology used, 92% of the students reported that working with problem-solving situations stimulated their initiative, creativity, and critical thinking. When asked about the contribution of teamwork to their motivation for learning, 69% of the participants stated that it led to a significant increase, while the others indicated a positive but less impactful contribution.

Technologies using Artificial Intelligence (AI) were incorporated into the course from the first day. The entire process of analyzing the students' use of these tools was done through observation, as the goal was not to evaluate performance in a summative manner but to follow their competency development over time. It was observed that initially, students showed apprehension and insecurity, especially in creating prompts and using the available resources properly. However, they gradually learned to balance decision-making regarding when and how to use AI, understanding that its use should be intentional and critical. Discussions throughout the course consistently emphasized the ethics of using technology, the importance of prior knowledge, and the role of individual creativity. Additionally, the positive potential of Artificial Intelligence in the teaching and learning process was highlighted, reinforcing the need to understand its functioning so that, in the future, they can use it consciously and effectively in their teaching practices.

5 Conclusion

The formative experience reported in this article highlights the transformative potential of Generative Artificial Intelligence (AI) in education when integrated in a critical, ethical, and context-sensitive manner for teacher training. By incorporating the project "Potentialities of Generative AI in Education" into the Digital Material

Production course, it was possible to provide students not only with technical mastery of new digital tools but also with a reflective experience on the pedagogical, social, and emotional impacts of using these technologies. The proposal aimed to promote ethical reflections, development of socio-emotional skills, and stimulate collaborative work—key aspects for the training of educators in the contemporary digital landscape.

The course structure—intertwining theoretical foundations, active learning, collaborative practices, and ethical-socio-emotional debates—proved effective in strengthening student engagement and enhancing the quality of the educational materials produced. The increase in face-to-face class attendance, coupled with the deeper discussions around AI ethics, indicates that student-centered, hybrid approaches sensitive to the complexities of technological mediation can foster more impactful learning experiences.

In summary, the results suggest that teacher training for AI use in educational contexts should go beyond technological tool mastery. It needs to be grounded in ethical values, the strengthening of human connections, and the promotion of socio-emotional competencies that facilitate welcome, dialogue, and authorship in the educational process. This reinforces the importance of adaptive, collaborative, and contextualized pedagogical practices that recognize AI as an ally in building a more just, critical, and humanized education.

It is important to note that the methodology described here can be replicated, with modifications based on contextual particularities, for teacher training in fields such as Pedagogy, Mathematics, or Engineering. The discussions on the benefits of applying the developed methodology to this cohort do not end here. These discussions and analyses are extensive and could not be fully detailed within the scope of this article. However, they are available for further review and will be described in future works.

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Human flourishing versus burnout syndrome in the university context: The case of Club 1943 - Karaoke at Tec de Monterrey

Gerardo Salvador González Lara¹, María Eugenia Morales Hinojosa², Manuel Cebal Loureda³, Raúl Carlos Verduzco Garza⁴

¹ Department of Humanistic Studies, School of Humanities and Education, Campus Monterrey, Tecnológico de Monterrey, Mexico

² Institutional Event Management Center, Campus Monterrey, Tecnológico de Monterrey, Mexico

³ Department of Humanistic Studies, School of Humanities and Education, Campus Monterrey, Tecnológico de Monterrey, Mexico

⁴ Associate Director of Department of Humanistic Studies, School of Humanities and Education, Campus Monterrey, Tecnológico de Monterrey, Mexico

Email: gsgonzal@tec.mx, emorales@tec.mx, manuel.cebral@tec.mx, raul.verduzco@tec.mx

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Abstract

The vocation of most engineering and science professors is admirable; however, designing educational models appropriate for today's students becomes a challenge that requires ongoing training and work in multiple aspects of teaching. This demand is a significant source of burnout syndrome, which is reflected in stress, physical and mental exhaustion, decreased academic productivity and intellectual vitality, and demotivation, among other symptoms. In December 2015, professors spontaneously selected a recreational and social space on campus with a novel element: karaoke; this element contributed to creating a sense of shared joy and freedom. This karaoke session took root naturally and was named Club 1943 Karaoke. It is currently held monthly and is attended by an average of 130 professors per session. This cultural phenomenon in the university setting is worthy of analysis as an element of cohesion and well-being for the faculty community. We started from the research assumption: "The karaoke at Club 1943 [on the Monterrey Campus of Tecnológico de Monterrey] is a cultural instrument that fulfills a necessary function in preventing, avoiding, and reducing the incidence of burnout syndrome in the academic community, and in promoting human flourishing in its professors." This research assumption was demonstrated using quantitative and qualitative indicators, and it was concluded that karaoke is a collective response of faculty to burnout syndrome and a trigger for their human flourishing. Based on the results, the institution decided to formally incorporate it into its economic budget as an investment and integrated it into the services it offers to its academic community by organizing it monthly. The institution conceptualized it as a model of coexistence and recreation to combat burnout syndrome and an opportunity to enhance human flourishing in professors. It can be replicated at other universities, and this research offers some recommendations for its implementation.

Keywords: Human flourishing, burnout, culture, karaoke.

1. Introduction

Following the social, political, and economic impact of the Industrial Revolution in Europe, and later in America and the rest of the world, groups or guilds of people emerged that identified themselves as social collectives engaged in work-related activity within the modern economic structure. Their identity represented, within the collective, unity, problems, challenges, and common interests, and externally, allowed them to express themselves as an active group within the machinery of industrialization. Thus, these forms of organization based on work life became fundamental spaces of socialization for millions of people, for their survival and that of their families. It is suggestive to remember the film *Modern Times* (Dir. Charles Chaplin / USA / 1936 / 83 min) as an example of this unionization process: "...it is a film that follows the life of a factory worker, who is affected by the frenetic pace of assembly line production, which ultimately leads him to lose his sanity. After a series of unfortunate incidents, he is imprisoned but escapes by chance. Once free, he finds himself struggling to survive in an increasingly modern industrial society." (Cultura/UNAM, 2023)

Thus, throughout the 20th century, labor collectives were formed by very different activities or groups of workers, who were inserted into the economically active population. Thus, industries of employees and

professionals focused on common economic and labor activity were globally formed, as is the case in the construction industry, the automotive industry, and the entertainment industry, to name just a few. In the academic context, the teaching staff constitutes a guild or collective like those described above, namely, groups of people with specialized training in their area of academic knowledge, with experience and knowledge in teaching/learning didactics, as well as for the development of competencies.

University professors are a group or professional collective with similar problems, concerns, challenges, and interests, with a very clear collective identity. Like all other professions, they face the conditions of the 21st century that particularly affect educational work. These factors include technological advances in general, information technologies, artificial intelligence, consumer habits, and other factors that impact current university culture.

It should be noted that, although the main theme of this conference focuses on identifying and sharing innovative teaching methods to connect professional development and active learning in students of various engineering disciplines, the main promoter of this project is the professor. Professors are the guides of this training, and their physical and emotional well-being are essential for their performance in front of students. Their human flourishing is considered a relevant factor that is present simultaneously and integrated into the teaching process for active learning, with a direct impact on the teaching process. Healthy, happy, harmonious, and enthusiastic professors inspire greater enthusiasm for the subject they teach and greater student engagement. A professor whose teaching work is integrated with their human flourishing achieves a communication and information process that is closer to students, further enhancing their intellectual curiosity and desire to learn.

As evidence of the presence of burnout syndrome in the current work environment, and especially in the work context of university professors, researchers have shared indicators of tiredness and exhaustion, and their impact on professors from different parts of the world, considering this data representative of the profession. According to Torres (2025), in Mexico alone, "75% of Mexicans suffer from fatigue due to work-related stress, according to data from the Mexican Social Security Institute (IMSS)." Amezcua (in Torres 2025) states that "professors are not exempt from suffering the consequences of this condition... *Being a professor is classified as one of the professions with the highest psychosocial risks such as burnout*" stated at the 2023 National Meeting of Professors of the Tecnológico de Monterrey. Garcia (2022) states that: "For organizations, burnout syndrome has negative consequences such as low productivity, absenteeism due to disability, resignations, an increase in accidents due to lack of concentration, and sometimes legal issues." Lozano Luviano (UNAM 2022) among the ways to deal with it suggests "support in decision-making, organization of work and personal time, and management of relationships in search of a better quality of life" and proposes that institutions should consider the resources invested in the face of Burnout syndrome as an investment in the health of their collaborators and/or as an expense.

Delgado (2019) states that "Institutions focus on the socio-emotional well-being of students, but who is taking care of that of educators?" since according to a study by the Robert Wood Johnson Foundation and the Pennsylvania State University (Penn State), "teaching is one of the most stressful professions in the United States. The stress suffered by teaching professionals affects their health, commitment, performance, and satisfaction, making it one of the professions with the highest turnover in history." 46% of professors report feeling stressed daily during the school year (in Delgado 2019). This is why she states that "educators also need support to manage their stress." A study by the Federal University of Rio Grande do Norte on sleep habits reported that "46% of high school professors were diagnosed with excessive daytime sleepiness. In addition, 51% reported poor sleep quality, which affects their performance and impacts their students' results... they negatively affect their students because they create a negative environment and low student performance..."

When professors are highly stressed, their students have more difficulty adjusting socially and performing academically.” (in Delgado 2019).

The Education Support organization claims that the mental health of British professors is in such poor shape that, according to a survey of 3,082 professors, 59% are looking to leave the profession, and 78% experience symptoms of mental health problems due to their job, yet 47% still go to work (Delgado 2023). The consulting organization RAND (2022) which surveyed 2,360 professors and 1,540 head professors found that educators have worse well-being than other professions, almost three-quarters of professors and 85% of head professors said they frequently experience work-related stress, in comparison, only 44% of workers in other areas gave the same response. Another example is from Peru, where 56% of professors suffered from stress problems in 2022. The study also concluded that this is because professors have a double workload since they are expected to be in charge of their students' education, attend to their socio-emotional needs, and attend to the needs of students' families (Velásquez 2023).

All the above has meant a transformation in the profile of today's professors, regardless of age, experience, or hierarchy; and especially for engineering schools, which are involved in this conference. There is no doubt about the vocation of most engineering professors; however, designing educational models appropriate for today's students becomes a challenge that requires ongoing didactic updates in multiple aspects: assessment systems, learning styles, rubric design, ties to public and private institutions, etc. The social well-being and mental health of professors are, without a doubt, undervalued and underestimated.

These new demands of the profession are also triggering new cultural practices within the profession itself to cope with the demands of this pace of life in a healthy way and with the least possible negative impact. A faster pace of life than ever before, impacting the professional and personal spheres, as well as families and communities close to the professors.

One of the common consequences of this pace of life is burnout syndrome, which is reflected in stress, physical and mental exhaustion, decreased academic productivity and intellectual vitality, and demotivation, among other symptoms. The consequences of this syndrome gradually increase and spread to other aspects of professors' lives, impacting their physical, mental, and emotional health and calling into question their indispensable professional contribution to humanity. In this context, recreational activities for professors within the institution, such as the 1943 Club Karaoke program, which is the focus of this article, are cultural instruments that serve to prevent, avoid, and alleviate the incidence of burnout syndrome in the academic community and promote human flourishing.

The research assumption (Hernández 2018) is: “The Karaoke of Club 1943 [of the Monterrey Campus of Tecnológico de Monterrey] is a cultural instrument that fulfills a necessary function to prevent, avoid and reduce the incidence of burnout syndrome in the academic community, to promote human flourishing in its professors.”

This research has the general objective of:

To demonstrate the importance of addressing these needs to maintain faculty occupational health within a university culture, resulting in greater willingness to implement new active learning teaching techniques with engineering students. And three specific objectives

- 1) Explain why an activity like the Club 1943 Karaoke a university cultural phenomenon worthy of analysis is.
- 2) Describe how it was implemented in a large group of professors at the Tecnológico de Monterrey, Monterrey Campus.

- 3) To demonstrate why it is an innovative way to prevent, avoid, or mitigate the impact of burnout syndrome and to stimulate the professor's human flourishing.

It should be noted that the team of authors of this work, in addition to their teaching and research work, are part of the administrative team that manages and monitors the "Club 1943 Karaoke" at Monterrey Campus.

This paper will first explain how this initiative works as a university cultural phenomenon and address the importance of these initiatives considering burnout syndrome and human flourishing. It will then describe the initiative's implementation, as well as an evaluation of the results and conclusions drawn from the exercise.

2. Development

In December 2015, the professors spontaneously selected a recreational and social space with a novel element: karaoke, where singing, dancing, clapping, smiling, and eating generated a shared sense of joy and freedom. Unexpectedly, this karaoke took shape naturally and was named Club 1943 Karaoke. It is currently held monthly, attended by an average of 130 professors, and has remained active, remotely, throughout the COVID-19 pandemic.

In 2016, the 1943 Club Karaoke was established for the socializing and recreation of the teaching community. The number "1943" refers to the year the Tecnológico de Monterrey was founded, on Monday, September 6th, 82 years ago. At the initiative of the "Honors" program then directed by Dr. Liliana Manrique and with the support of Dr. Alfonso Serrano, the space was equipped one afternoon with microphones, sound equipment, and screens to foster artistic expression. Over time, this space became a model of informal and spontaneous socializing among colleagues. Initially, some colleagues timidly took the microphone to participate in these gatherings. Encouraged by the heartfelt applause, more and more colleagues gradually began to sing and dance, setting the tone for future sessions. In subsequent meetings, through a song selected individually, as a duet or as a team, this group of professors shared smiles and discovered themselves in a phenomenon that the Russian literary theorist Mikhail Bakhtin associated it with carnival: a primitive joy, a sense of brotherhood and liberation that united them as a community. Thus, the 1943 Karaoke Club was formed.

2.1 Theoretical basis of the university cultural phenomenon.

What role does the university professor play in this 21st-century educational model differ from previous periods? According to Ayala (2002), in the 21st century, the role of the traditional professor is now also that of an advisor who shows trust and respect for the diverse development possibilities of each of their students, which motivates them to seek the most effective way for them to achieve comprehensive training. Fulfilling this new attribute of the professor generates greater formative responsibility and training demands in many ways, not only in the specialized area of knowledge; faced with this additional workload, moments are required to release tension and reduce the exhaustion that this responsibility entails.

Mexican anthropologist Bonfil (1987) proposes the concept of a cultural instrument as a means of understanding a specific culture. For Bonfil, a cultural instrument is "any collective act with a common social purpose" (108) that generates identity and unity within a group, such as the phenomenon analyzed here. The types of cultural instruments Bonfil refers to are material, demographic, organizational, knowledge, symbolic and communication, and emotive or subjective. Thus, Club 1943's karaoke is identified as a symbolic and communication cultural instrument, as it is a practice that influences integration and socialization among professors; and also an emotive or subjective type of instrument, due to the affection and friendship that are strengthened within a group, a product of the affective motivation for integration into the group that each professor integrates into this community.

With suspicious, joyful glances and sincere collusion, a group of established, new, and emeritus professors from all disciplines—researchers, established authors, and those with a variety of academic and scientific accolades—

come to the evening gathering at the Monterrey Campus. They aim to shed their intellectual prestige and become witnesses and protagonists of a carnivalesque cultural phenomenon, revealing themselves as living elements of the celebration and culture of laughter proposed by the Russian philosopher Mikhail Bakhtin (1875–1975).

In 2002, researcher Tatiyana Bubnova gave a lecture at the Monterrey Institute of Technology, Monterrey Campus, entitled "Party, Rupture and Transgression, according to Bakhtin," to explain the theoretical proposal of the Russian theorist in his work *Popular culture in the Middle Ages and the Renaissance*. According to Bubnova (2002), Bakhtin (1995) proposes reading the festivals and celebrations as a transhistorical cultural phenomenon of Humanity, whose function is to transgress the social reality of a given moment in order to confront, through catharsis and collective rejoicing, the structures and hierarchies that keep all people in certain roles, submissions, obligations, norms, silences, among many other forms of social pressure and that, as a whole, make up the entire machinery of a social structure. Thus, within an apparent sense of freedom, a moment of celebration and collective enjoyment becomes a sublime time that returns us to the liberating origin of Humanity. By human nature, primitive men and women, by identifying each other as necessary and vulnerable, when they managed to survive the uncontrollable forces of nature, formulated the need to celebrate with expressions of joy and group security through shouts, laughter, body language movements and within a collective hubbub.

This phenomenon is observed in the teaching community that attends the Club 1943 Karaoke to confront, for an afternoon and with an apparent sense of freedom, the established social order, although after that moment of liberation everything returns to normal.

2.2 Theoretical support from burnout syndrome and human flourishing

As explained above, in the current work environment, professors are overwhelmed and immersed in uncertainty, subject to constant training demands, academic and administrative requirements, and simultaneously developing research projects in their specialty and in educational innovation. In this context, teaching staff are exposed to burnout syndrome. Quirónprevención (2018) defines this syndrome as follows:

The syndrome of *Burnout*, or "burned-out worker syndrome," refers to the chronic nature of work-related stress. It manifests itself through a state of physical and mental exhaustion that lasts over time and can alter a worker's personality and self-esteem. It is a process in which workers gradually lose interest in their tasks and develop a negative psychological reaction to their job.

Causes of burnout include work overload, lack of time to complete tasks, excessive responsibilities, stress (performance demands, lack of support from superiors), lack of autonomy in one's work, lack of recognition from superiors, a negative work environment, as well as individual factors such as a tendency toward anxiety, lack of boundaries, and difficulty saying no.

The physical symptoms of this syndrome include physical exhaustion, chronic fatigue, difficulty sleeping, lack of energy, headaches, muscle tension, gastrointestinal problems, changes in appetite, and changes in the menstrual cycle.

Emotional symptoms that often manifest include a feeling of failure, disinterest in work, loss of motivation, irritability, cynicism, anger, impatience with colleagues and clients, a constant state of anxiety and nervousness, difficulty concentrating, feelings of sadness, hopelessness, loss of interest in activities, decreased self-esteem, and skepticism about one's own abilities and capabilities.

Behavioral symptoms include social and professional withdrawal, difficulty interacting, reduced productivity, procrastination, lack of attention to tasks and work commitment, and absenteeism.

Given this phenomenon in the university workplace, it is necessary to create a space for faculty members, following the theoretical proposals of Bonfil and Bakhtin, to experience a catharsis that provides a sense of liberation and shared joy, enabling the group to integrate, strengthen, and regain the prudence, energy, and good spirit to carry out their university work and thus achieve human flourishing.

For the Monterrey Institute of Technology (2024), human flourishing:

It is a personal and conscious process of developing capacities in all areas of life, in which each person relates to the community and the environment to create a better world, respecting their own dignity and that of others... [even when carried out in a community] the person is the center. It is a conscious process that responds to personal convictions, purpose, and actions. It is a process interrelated with the conditions of the social and environmental context. Human flourishing is an end in itself.

Professors must be aware of their own human flourishing to foster it in their students, integrating it into the teaching process within the university setting, that is, in the classroom or laboratory. Therefore, teaching must be complemented by the integration of cultural, cathartic, and personal harmony aspects to be able to give themselves to others, enjoying personal fulfillment in every sense.

3. Implementation of the “Club 1943 Karaoke” for the teaching community

What is karaoke? The Royal Spanish Academy defines it as: "Entertainment consisting of singing a song to a recorded musical background, while following the lyrics displayed on a screen. [It includes] the technical equipment consisting of a sound amplifier, microphone, etc., used for karaoke.

And who is the architect of this cultural phenomenon at Tec de Monterrey? The Monterrey Campus Events Management Department is responsible for Club 1943, led by Martha Maqueo until December 2024 and currently by Emma Inés Cortés, with a valuable team comprised of Alejandra Silva, Cecilia Ordaz, Jorge Tello, Marvin González, Oscar Rodríguez, and María Eugenia Morales.

First, a large, enclosed space on Monterrey Campus is selected monthly, open from 5:30 to 8:30 pm, with exclusive access for professors. Sound equipment is installed, along with a computer to connect to a karaoke website, and four microphones are set up in front of the venue, with a stage-like space. Twelve round tables, each clearly numbered from 1 to 12, are arranged, each with ten chairs. Upon arrival, each teaching assistant sits down and chats freely with their tablemates. The Club 1943 Karaoke Lead Professor brings the program and invites the tables to participate; he asks the name of the song, making humorous, upbeat comments that contribute to the integration. Each table forms a team and decides which song to perform, the musical genre, and the number of members who will appear on stage (an individual singer, a duet, or all members of the table). It's important to note that, although the current table decides which song to perform and/or dance to, the other professors at other tables are free to join them in singing or dancing, which is the case most of the time. During the three-hour event, an average of 45 songs are sung, and each table can sing four times. The Event Management Department invites guests to dinner (tamales, tacos, a buffet of casserole, hamburgers, etc.), soft drinks, beer, cake, and coffee; the amount of food is calculated from the list of professors registered for the event at least ten days in advance. The invitation is extended to the general academic community via email.

María Eugenia Morales is the Leader of the Events Management Department, which organizes graduations, degree signings, start-up and end-of-semester events, Professors' Day, etc., and thanks to what this work has demonstrated, starting in 2022, Club 1943 Karaoke has been formally integrated into the institutional events of the Monterrey Campus.

María Eugenia Morales, co-author of this work, has been with her *Alma Mater* for 34 years and has also collaborated in various venues such as the Library and the Book Fair. She states: "The purpose of the Club 1943 Karaoke is to provide the teaching community with a space for recreation and fun, something different from what is, for them, the reason they exist at Tec de Monterrey. It's extremely necessary for them to have a moment of relaxation and forget about their daily activities, de-stress, and set aside their academic pursuits to meet and socialize with colleagues from different areas." Regarding the experience of creating the Club 1943 Karaoke space, she asserts: "The truth is, it's been very well received with very good results. Many have approached us requesting its organization and inquiring about upcoming dates. We like that because it means we're doing things right by filling a necessary space, and with the exact characteristics demanded by the academic community of our campus; karaoke truly fulfills its purpose".

The results of the Club 1943 Karaoke prompted the institution's authorities to allocate the necessary budget for its monthly celebration, open to the entire teaching community, whether on a full-time or subject-based contract.

4. Evaluation of results

The methodological approach of this research was quantitative and consisted of applying a total of 1058 virtual surveys to the attending professors via institutional email, one, two, or three days after fifteen sessions of Karaoke 1943. The professors surveyed were identified by School or Faculty, and whether they had attended previously or it was their first time, and they numerically evaluated their level of satisfaction with the Club 1943 Karaoke event. To complement the qualitative research, two testimonies from ten professors were selected to illustrate the experience of their participation in the event.

Quantitative results. Fifteen feedback surveys were administered to professors after the Club 1943 Karaoke sessions held between August 2023 and March 2025.

Table 1. This table indicates the date, year, attendees, first occasion of attendance and an average evaluation of the event, following the Likert scale, where 1 corresponds to the highest degree of satisfaction and 5 to the lowest degree of satisfaction.

Table 1. List of activities

Event	Weekday	Day	Month	Year	Professors	New professors	Evaluation
Karaoke	Tuesday	15	Agost	2023	77	NA	1.24
Karaoke	Wednesday	23	Agost	2023	16	NA	1.08
Karaoke	Tuesday	12	September	2023	54	NA	1.3
Karaoke	Tuesday	3	October	2023	62	NA	1.26
Karaoke	Tuesday	7	November	2023	61	NA	1.22
Christmas party	Tuesday	5	December	2023	100	NA	1.08
Karaoke	Wednesday	21	February	2024	59	12	1.2
Karaoke	Tuesday	19	March	2024	69	12	1.2
Karaoke	Wednesday	12	June	2024	85	6	1
Karaoke	Monday	19	Agost	2024	87	11	1.1
Karaoke	Wednesday	11	September	2024	88	12	1.1
Karaoke	Friday	11	October	2024	80	7	1.2
Karaoke	Monday	11	November	2024	92	8	1.1
Christmas party	Tuesday	3	December	2024	135	18	1.1
Karaoke	Monday	10	March	2025	80	6	1.1

Feedback surveys were conducted on these fifteen occasions, one day after each Karaoke 19.43 event. The number of participants varied, most likely due to the time of year at which the event was held. The overall evaluation of the event, considering the time, location, food, and atmosphere, averaged 1.15 on a Likert scale, where 1 corresponds to the highest level of satisfaction and 5 to the lowest level of satisfaction.

Table 2. This table shows the attendance of professors to the Karaoke Club1943 initiative, based on the surveys answered during the period 2023-2025, indicated by gender, as well as the number of professors in the School of Engineering.

Tabel 2. Attendance

Professors	Aug to Dec 2023	2024	Until March 2025
Women	110 = 53%	123 = 49.80%	40 = 50%
Men	98 = 47%	124 = 50.20%	40 = 50%
Total Professors	208 = 100%	247 = 100%	80 = 100%
Professors of the engineering school	91 = 43%	89 = 36%	36 = 44%

Interpretation. Table 2. Gender equity in attendance at this initiative is very evident, validating it as a need for the academic community. The average attendance rate for faculty members at the School of Engineering is 41 percent, the highest among all schools.

Table 3 shows the information from the different Academic Departments of the Monterrey Campus of those who regularly attend Club 1943 Karaoke.

Table 3. Academic departments

Period	From how many academic departments did the professors attend on Monterrey Campus?
From August to December 2023	Professors from 40 different Academic Departments
Year 2024	Professors from 50 different Academic Departments
From January to March 2025	Professors from 36 different Academic Departments

Interpretation: The Club 1943 Karaoke teaching performance initiative has impacted on the entire academic community of Monterrey Campus since professors from

Qualitative results are represented by two testimonies:

X1, professor at the engineering school, affiliated with the Women in Science initiative, member of the National System of Researchers, winner of the Tec Women's Award, and Full Professor, offered her testimony in an interview, in which she stated:

For me, [Club 1943 Karaoke] is a space for relaxation and socializing with colleagues from different schools in a healthy, friendly environment... My [work] hours are very long, and going in the afternoon seemed impossible, but when I went [to karaoke], I was captivated by the healthy, friendly atmosphere, because everyone is welcomed and there's a lot of empathy. So, thank you very much and congratulations to the organizers, they're great!

- What do you consider to be its function? -:

Foster bonds of empathy, solidarity, and friendship beyond the classroom.

- And how do you see Club 1943 in three years' time?

With greater institutional recognition, where resources are provided so that more and more colleagues become aware of it and have access to activities that promote holistic well-being.

X2, Chemical Engineer and professor at the School of Engineering and Sciences, states:

For me, Club 1943 Karaoke is a space to socialize with other professors, dancing, and sharing the joy of life. I'm not a good singer, so I prefer to enjoy other classmates' singing, and even better, when the song is right, to dance together with other colleagues. I believe that karaoke is essential in the university environment at Tec de Monterrey, as an outlet for the stress we experience as professors and for creating a unique atmosphere of camaraderie that allows us to fully enjoy these moments. All of our karaoke sessions are very enjoyable, but I especially like the ones in December because we share a video of everything we've experienced and enjoyed throughout the year. And at the end, we sing Christmas carols together and wish each other Happy Holidays.

- And how do you see Club 1943 in three years' time?

I'm sure Club 1943 will continue in the future and that more and more professors will join events like karaoke. Many thanks to the organizers of the Club 1943 events for giving us the opportunity to have these wonderful get-togethers at Tec of Monterrey.

5. Conclusions

Throughout this study, the value of Club 1943 Karaoke was confirmed as a cultural instrument that serves to prevent, avoid, and alleviate the incidence of burnout syndrome in the academic community of Tecnológico de Monterrey, especially among professors in the School of Engineering and Sciences, as well as promoting the human flourishing of the academic community. Likewise, the fulfillment of the objectives set forth at the beginning of this work is observed. Particularly noteworthy is that during the period covered by this research on the impact of Club 1943 Karaoke on professors at Monterrey Campus, 40 percent of whom are from the Engineering School and are the faculty with the greatest presence. The remaining 60 percent are distributed among more than seven schools, which is evidence of the need that this monthly event meets among this entire group of professors.

Given the experience and lessons learned over the nearly ten years of this initiative, as well as the significant impact it has had on the teaching community, academic authorities at other universities are invited to consider and value it in the same way, benefiting the physical and emotional health of their faculty members. This benefit will greatly impact and be reflected in the effectiveness of the teaching/learning processes carried out by faculty members, as well as in encouraging the development of competencies in their students. Allocating a budget, time, and space for a university cultural instrument such as the one described is an investment with benefits for the occupational health of the community, for combating burnout syndrome, and for stimulating faculty development, which is reflected in teaching practice, in the eyes of the student community, and in society at large.

The research assumption was verified: "The Club 1943 Karaoke [at the Monterrey Campus of Tecnológico de Monterrey] is a cultural instrument that fulfills a necessary function to prevent, avoid, and reduce the incidence of burnout syndrome in the academic community, to promote human flourishing in its professors " and the general objective was achieved: To demonstrate the importance of addressing these needs to take care of the occupational health of the professor within a university culture, so that it results in a greater willingness to implement new active learning didactic techniques in engineering students. And also, the three specific objectives: 1) Explain why an activity like the Club 1943 Karaoke a university cultural phenomenon worthy of

analysis is. 2) Describe how it was implemented in a large group of professors at Tecnológico de Monterrey, Monterrey Campus; and 3) Show why it is an innovative way to prevent, avoid, or alleviate the impact of burnout syndrome and stimulate the human flourishing of the professor.

The implications of this research for higher education in engineering are highly likely due to the benefits of human flourishing in the development of professional professors. Given the importance of physical and emotional health in the teaching and development processes, as well as in the development of competencies, active learning will be better implemented in daily teaching activities. It is asserted that a stress-free professor who manages to confront burnout syndrome and develop their human flourishing will be a better engineering professor, will identify with a sense of community and a shared teaching vocation, and will be a fully fulfilled individual.

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Bridging Industry and Academia through Project Based Learning

Olga Bernaldo¹, María-Cruz Gaya¹, Pedro J. Lara¹, Alberto Sols¹

¹ School of Architecture, Engineering and Design. Universidad Europea de Madrid, Villaviciosa de Odón, Spain

Email: mariolga.bernaldo@universidadeuropea.es, mcruz@universidadeuropea.es, pedro.lara@universidadeuropea.es, alberto.sols@universidadeuropea.es

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Abstract

The need to establish real synergies between the university environment and the world of work so that the student faces his academic career at the university from a business perspective, where the study of the different subjects does not represent something isolated but rather a compendium of knowledge of a holistic nature, with real and practical applicability, has led the Steam school of the European University to develop a concrete and specific academic model that has meant introducing important changes to adapt to the project-based learning methodology (PBL). This article explains the changes that have been implemented since 2012 and the implications that this has had on the teaching staff, who have had to adapt through continuous and specific training in the PBL methodology, in the adaptation of the facilities to facilitate the realization of projects, and in the relations with the business sector for collaboration in the design and development of proposals. Feedback consistently received over the years from many stakeholders, as well as from alumni after having been working for several years, leaves no doubt: project-based learning makes students engage more, learn better, and is much more effective for them to develop the set of soft skills required by companies. The three pillars on which the implementation of the PBL methodology is based, teacher training, transformation of facilities and collaboration with industry have contributed significant improvements to the academic model of the Steam School of the European University and to the way in which our students face their professional future. When project-based learning is coupled with a strong industry partnership, learning results skyrocket. Students not only acquire and master the necessary knowledge to graduate; they gradually develop the set of soft skills, such as teamwork, resilience, communication skills, and proactivity.

Keywords: Project Based Learning (PBL); Industry and University; PBL Ecosystem; Practical experience.

1 Introduction

1.1 University role

Universities are institutions of higher education, usually comprising colleges in different areas of knowledge, and with the recognized capability of granting degrees in those areas. As we know them today, universities arose in western Europe in the Middle Ages, although precursors existed in Africa and Asia in ancient times. Modern universities are an evolution of medieval schools known as “studia generalia”, which usually arose out of efforts to educate clerks and monks beyond what was addressed in the monastic schools.

In modern society, in which labour is highly specialized, universities are the institutions focused on developing knowledge and expanding the frontiers of what is known, through research, as well as on passing the existing knowledge to the new generations, through education, preparing them for the professional life [28, 33].

1.2 Drawbacks of Traditional Approaches

The role of universities in modern society is to educate and prepare new generations to be future researchers and professionals in a constantly changing society, contributing to the business world, research, and society at large [28]. However, academia and industry often lack alignment, resulting in graduates facing a gap between their education and industry expectations, especially in soft skills [29], [36].

Several drawbacks of the conventional teaching approach include:

- a) Different Atmospheres: Faculty often lack industry experience, making it difficult to prepare students for real-world environments [26].
- b) Lack of Practical Experience: While some subjects don't require industry experience, others, like Software Engineering and Supply Chain Management, benefit greatly from it [11].
- c) Lack of Project Execution: Unlike industry, academia rarely organizes activities like projects. Projects help students develop teamwork, resilience, and communication skills, which are often missing in traditional education [35].
- d) Separation of Domains: There is often a lack of communication and feedback between academia and industry, which needs to be addressed to fulfill the university's third mission [31].

1.3 The Origins of Project Based Learning at STEAM School

Project-Based Learning (PBL), based on Learning by Doing [5, 18], is widely adopted by secondary and higher education institutions [21]. Aalborg University [2, 19], a pioneer in PBL, promotes multidisciplinary project-based education, yielding better results through active student involvement [4, 24]. Since Kolb's experiential learning model [20], research and innovation in PBL have flourished [16, 32], showing positive impacts on student motivation [8, 22, 35].

PBL has been applied across various areas, subjects, and curricula. Some authors relate PBL to design thinking [12], while others use it for teaching computational thinking [15]. PBL is also used for learning agile models in Software Engineering and Design [3, 25], and non-technical subjects [30]. Many engineering schools use PBL for training future engineers, either in individual subjects or throughout the curriculum [17, 23].

The CDIO (Conceive, Design, Implement, Operate) initiative complements PBL in engineering education. Adopted by over 200 schools, CDIO and PBL share the philosophy of providing practical educational experiences. CDIO focuses on developing engineering competencies through a project's life cycle, while PBL emphasizes solving complex projects that foster critical thinking and collaboration [9, 14].

At the STEAM School of Universidad Europea de Madrid (UE), the motivation in 2012 was to make students feel like engineers from day one. Traditional theoretical classes were supplemented with practical activities, but small projects rarely transcended beyond their subjects. PBL aims to offer practical learning that facilitates knowledge transfer to the professional world [16, 25, 31, 38]. However, some authors identify challenges in this transfer [8]. To address this, [7] suggests gradually introducing innovative methodologies from early courses.

In 2012, the STEAM School began its journey towards a project-based learning ecosystem [34]. This ecosystem includes practical learning in all subjects, early-year projects, integrative projects across subjects and degrees, and informal project-based learning through student clubs.

2 Pedagogical Framework. Evolution of PBL at STEAM School

2.1 The three pillars: faculty, facilities, and industry links

Throughout the last decade, the STEAM School has developed initiatives in three directions: training faculty, transforming facilities, and bridging the gap between school and industry.

Faculty Training: Training faculty in PBL methodology is essential [23, 30]. This has been achieved through specific training programs, tools for classroom use (e.g., project templates, evaluation rubrics), and periodic meetings to share best practices. Additionally, the faculty has been balanced between academic and industry professionals to use current technologies in project development.

Facility Transformation: Creating facilities that promote project work is crucial [17, 36]. This includes opening spaces for undergraduate students, involving physical and cultural changes, and modifying management practices. A workspace of over 400 square meters has been created for group projects, along with an advanced computing center with over 700 cores for real projects.

Industry Collaboration: Project-based learning is more effective with industry participation [8]. Inspired by the Triple Helix Model [6], the school has established collaboration agreements with companies as Strategic Allies and Industrial Partners. These companies participate in project design, development, and evaluation.

In summary, the methodology has been implemented through faculty training, facility transformation, and industry collaboration over the past 12 years.

2.2 12-Years Experience

During the year 2023/2024, we will celebrate the 12th anniversary of applying PBL to all degrees at our STEAM School at UE, now called Project Based School (PBS). This section describes the experience accumulated over these twelve years. The implementation of PBS has three main phases: (i) introducing projects as learning activities across several subjects, (ii) integrating projects as specific subjects in our curricula, and (iii) PBL 2.0 to enhance the methodology used by teachers.

2.2.1. Projects as Learning Activities

Each academic year, students embarked on comprehensive projects that partially covered the content of multiple courses, with various instructors contributing. These integrating projects were designed only with courses of the same year (horizontal integration), but they could belong to different quarter periods. The aims were: (i) enhance motivation and sense of belonging among students and teachers, (ii) facilitate deeper learning of specific engineering skills, (iii) develop and promote generic skills like teamwork, communication, independent learning, and effective planning, and (iv) establish a connection between the classroom and the engineering profession, enabling students to solve practical and real-world problems.

Three factors contributed to the initiative: (i) the decision made at the school's management level, (ii) a teacher training program on the methodology, and (iii) an integrated project template to align teachers and program leaders. The findings revealed promising results: increased motivation for both teachers and students, deeper understanding of specific and generic skills, and appreciation for projects involving external companies. However, areas for improvement include specialization within project groups and the need to emphasize sustainability in projects.

2.2.2. Projects as Subjects

In 2015, the school revised the PBL approach and implemented project-based courses in all undergraduate engineering programs. These courses applied knowledge from subjects taken during the same or previous academic years within practical projects. In the first year, students practiced basic engineering competencies (math, physics, programming, and business) in an "Engineering Project." In the second year, computer engineering skills were developed in a "Computer Science Project," divided into two subjects (one per semester). In the third year, the degree specialization was carried out through a "Computation Project," focusing on advanced databases, artificial intelligence, and user interfaces. No projects were conducted in the fourth year to dedicate more time to the mandatory final degree project.

Quantitative analyses from the 2021-22 academic year revealed that PBL methodology in project-focused courses provided students with experiential learning opportunities, solidifying theoretical knowledge and developing cross-cutting skills like teamwork and problem-solving. Student motivation improved, reducing dropout rates significantly. Interviews with graduates indicated enhanced competencies in teamwork, project

management, and decision-making, along with a deeper understanding of technical skills, reflected in improved pass rates in traditional subjects.

2.2.3. PBL 2.0

In the 2022/2023 academic year, we pursued three primary objectives: (i) establishing a uniform vocabulary for all teachers regarding PBL implementation, (ii) disseminating this shared vocabulary among faculty members, and (iii) providing teachers with methodological tools for effective classroom application. This ecosystem is described in the next section.

3 Project-Based Learning Ecosystem; Growing as a Learning Organization

To grow as a learning organization, a PBL ecosystem was developed at the school. Learning organizations are characterized by a true learning culture and atmosphere, where learning to learn is essential for everyone involved. They have a shared vision, which motivates collective and sustained action in a psychologically safe environment [15], [13]. The ecosystem is captured in the School's Knowledge Map.

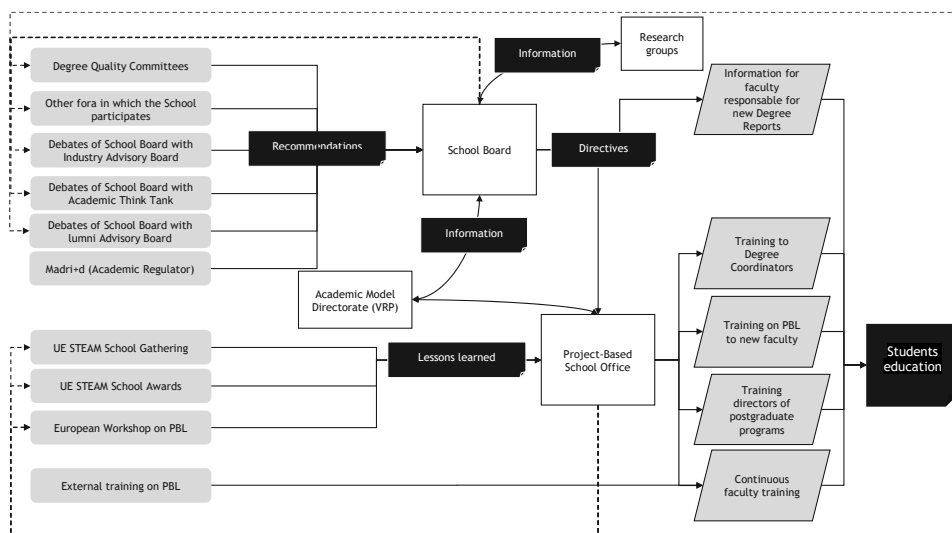


Figure 1. School Knowledge Map. (Source: own elaboration)

The main entities in the ecosystem, centred around the School Board and the Project-Based Office, include:

1. **Think Tanks:** Advisory boards in higher education institutions improve curriculum, student competency development, and student interaction with the professional environment [25]. The School Board has three think tanks: the Industry Advisory Board with 22 professionals from various industries, the Academic Think Tank with 10 senior faculty members discussing internal school topics, and the Alumni Advisory Board maintaining a close link with alumni to engage with the growing community of graduates.
2. **Faculty Gatherings:** Communities of practice provide an enriching environment for continuous learning, professional development, and collaboration [35]. Each academic year, students carry out hundreds of projects. In July, several professors present their project organization and results to the faculty, enabling the sharing of best practices and collective learning.
3. **School Awards:** Awards are a proven form of motivation among students [8]. In September, the best projects in each category participate in the School Awards. Students present their artifacts or technology demonstrators, accompanied by a video showing project selection, execution, and results. Companies attend the ceremony, and their representatives vote to elect the winners.

4. European Workshop on Project-Based Learning: Every November, the school hosts the European Workshop on Project-Based Learning, facilitating external benchmarking with other European universities. Best practices, experiences, and problems are shared for continuous improvement.
5. Strategic Allies and Industrial Partners: Collaboration between universities and industry enhances innovation through knowledge exchange [1]. The school has strong relationships with industry, faculty, and facilities, forming the three pillars of the academic model. Strategic Allies are companies actively participating in program design, academic activities, facility requirements, and methodology improvement.
6. Academic Model Directorate: Within the Office of the Provost for Faculty and Research, the Academic Model Directorate establishes experiential learning academic model guidelines for the university.

The PBL Agenda is a living document composed of collectible cards that help teachers understand and implement Project-Based Learning (PBL) at the STEAM School. Each card provides concise summaries of essential information for PBL methodology. They are distributed during quarterly meetings, with new content added regularly. Key sections include motivational explanations, guidelines for project design, implementation, and assessment, recommendations, contact information for support, indicators, achieved results, phases of 'Implementing a PBL 2.0 Project,' guidelines for effective feedback, and instructions for constructing assessment rubrics. Additional cards are introduced at each quarterly faculty meeting.

4 Main Results

During these eleven years of PBL implementation in the STEAM School degrees an annual average of 30 projects based on the methodology has been generated. These projects involved an average of 12 degrees, 120 students and 65 teachers. Figure 2 shows the evolution of the number of projects in the last decade.

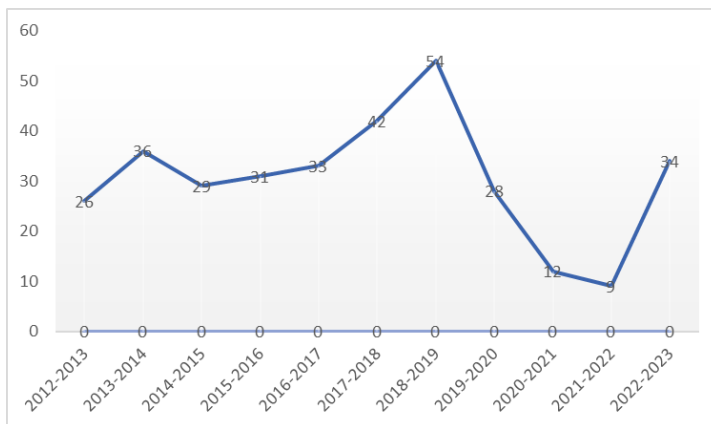


Figure 2. Projects per course (Source: own elaboration)

This graph shows the significant increase in the number of projects that have been carried out in the Steam School with the PBL methodology until the 2018-2019 academic year. From then on, the impact of the pandemic caused a decrease in the number of projects, data that, given the exceptional circumstances that were experienced and the difficulty of many students in regularly following classes, is considered very positive and indicative of a solid implementation of the methodology. The increase in the number of projects in the 2022-2023 academic year and the forecasts for the 2023-2024 academic year outline a scenario of growth and alignment of the subjects with the methodology.

These results highlight a fairly equitable distribution of projects in the 4 areas in which the school is structured.

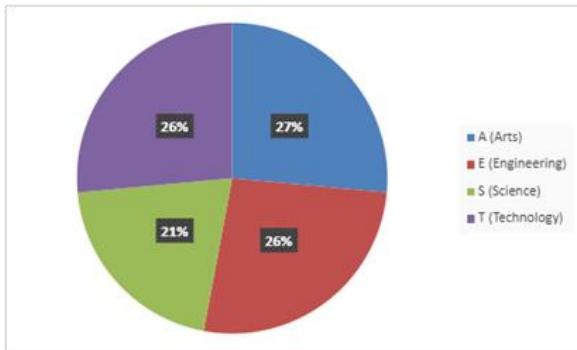


Figure 3. Distribution of projects by areas (Source: own elaboration)

In 2016, the European University implemented a satisfaction survey to assess the impact that teacher training in PBL Methodology was having on the project-based learning approach carried out in the classroom. This survey has yielded values that reach 84.2% of student satisfaction, where the improvement in the solidity of learning theoretical concepts, in the development of transversal skills such as teamwork and problem solving, as well as in improving your motivation.

In addition, former students have told us about the high degree of acceptance and integration in the world of work and what they appreciate in companies that the students have developed their academic career in scenarios like those used in the business field.

On the other hand, companies have expressed their satisfaction with the APB model in two aspects, one when they participate as a jury in the UE Steam School awards where they can visualize and judge the quality and rigor of the projects and another when these students join their companies where they demonstrate their technical knowledge and "soft" skills such as teamwork, responsibility, autonomy, ease of communication, etc. I literally transfer one of the opinions linked to participation as a company jury: "I take this opportunity to thank you for your involvement in these awards which, from my point of view, are very interesting for all parties, and above all and especially for the students. Congratulations on the work and the result"

5 Conclusions and future lines of research

Feedback consistently received over the years from many stakeholders, as well as from alumni after having been working for several years, leaves no doubt: project-based learning makes students engage more, learn better, and is much more effective for them to develop the set of soft skills required by companies.

The three pillars on which the implementation of the PBL methodology is based, teacher training, transformation of facilities and collaboration with industry have contributed significant improvements to the academic model of the Steam School of the European University and to the way in which our students face their professional future.

When project-based learning is coupled with a strong industry partnership, learning results skyrocket. Students not only acquire and master the necessary knowledge to graduate; undertaking challenges and working in projects they gradually develop the set of soft skills that are so important and necessary, such as teamwork, resilience, communication skills, and proactivity.

To deliver better education, in the broadest sense of the term, project-based learning with a strong industry partnership is highly encouraged.

The future lines of research proposed by the Steam School of the European University of Madrid to improve the model are focused on the design of a continuous improvement system through the definition of a control

panel that contains KPIs that allow evaluating the degree of maturity of the implementation of the methodology and that, in addition, makes it possible to establish comparisons with other Higher Education Institutions and measure the evolution of the institution itself over time. These KPIs are also intended to provide empirical evidence on the effectiveness and impact of AI (Artificial Intelligence) in the development of PBL projects and the acquisition of learning results by students, as well as on the effectiveness and impact of PBL in the development of technical competencies on AI and in the development of a theoretical and methodological framework for the integration of AI with PBL.

In summary, the following research questions are posed: Is there a standard methodology that identifies how to implement a continuous quality cycle in the implementation of PBL in higher education institutions? If not, how could it be defined? On the other hand, what impact do new AI tools have on the development of PBL? Does PBL help to avoid the risks of LLMs regarding authorship of works? Is PBL a good tool for teaching the use of AI tools?

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Formative Assessment by Biomedical Engineering Students to Enhance Learning

M. Teresa Monteiro¹

¹ ALGORITMI Centre, Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal

Email: tm@dps.uminho.pt

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Abstract

This article intends to share insights from a pedagogical experience during the academic year 2023-2024 involving 64 students, in the Numerical Methods course in the Biomedical Engineering graduate program at the University of Minho, Portugal. The assessment consists of two summative tests worth 80% of the final grade. Each test comprises a theoretical-practical component and a practical one using MATLAB software. To engage students in the teaching-learning process, prepare them for assessments, and evaluate their progress, two formative tests are proposed before summative test. The formative tests, worth 20% of the final grade, are proposed, solved, and revised by the students. The class is divided into 16 teams of 4 students, and the subject matter into 16 topics. In the first formative test, 8 teams propose an exercise related to one of 8 topics (preferably related to Biomedical Engineering). The remaining 8 teams each solved one of these proposed exercises. The resolution of the exercise is assessed by the proposing team (peer revision). In the second formative test the teams switch their roles for the other 8 topics. The selection of topics among the teams is random, as well as the teams proposing and solving the exercises. The criteria assessment of the team considers: i) proposal of the exercise (creativity, suitability, complexity, real-world application, etc.), ii) assessment of the resolution made by the solving team, iii) exercise solving. A padlet, with a column for team, contains all the proposed exercises, resolutions, and the solving revision. A review of all the course contents is carried out being available online to all students. This experience promotes higher levels of student engagement, performance and satisfaction, promoting their involvement in learning, cooperation, peer revision and the personal construction of knowledge.

Keywords: Formative test; Peer Revision; Problem-Formulation; Problem-solving.

1 Introduction

A truly student-centered approach to education requires assessment practices that are also focused on the student, both working together to promote meaningful learning. Yet, assessment remains one of the least transformed areas of higher education pedagogy. Traditionally, it has emphasized summative, teacher-led evaluation - assessment of learning - that often excludes students from the process. In contrast, student-centered assessment shifts the focus to supporting learning. It includes formative, feedback-driven approaches - assessment for learning - and encourages students to take an active role through assessment as learning, engaging in metacognition, critical thinking, and self-evaluation.

The way students are assessed significantly shapes how they approach their learning and the skills they develop (Brown, 2021, Struyven, Dochy, & Janssens, 2005).

Formative testing plays a crucial role in higher education by enhancing student learning, promoting active engagement, and providing valuable feedback for both students and instructors. Unlike summative assessments, which evaluate overall performance at the end of a learning period, formative tests are designed to monitor progress, identify knowledge gaps, and guide students toward deeper understanding (Black & Wiliam, 1998).

One of the key benefits of formative testing is its ability to reinforce learning through the testing effect, a cognitive phenomenon where retrieving information strengthens memory retention (Roediger & Karpicke, 2006). Regular low-stakes assessments help students consolidate knowledge, making it easier to recall during

high-stakes exams or real-world applications. Additionally, formative assessments encourage self-regulated learning, as students become more aware of their strengths and areas for improvement, allowing them to adjust their study strategies accordingly (Nicol & Macfarlane-Dick, 2006).

From an instructional perspective, formative tests provide educators with actionable insights into student progress, enabling them to tailor teaching methods and address misconceptions before they become deeply ingrained. This approach fosters a more adaptive and student-centered learning environment (Sadler, 1989).

Formative testing is a powerful educational tool that supports continuous learning, self-assessment, and knowledge retention. Its integration into higher education curricula can significantly improve academic performance and overall student development.

A formative test can take different formats, such as quizzes, concept maps, peer assessments, reflective journals, problem-based exercises, oral questioning and discussions. Using a mix of methods keeps students engaged and caters to different learning styles (Shute, 2008). In this experiment, the formative test is created, solved, and assessed by students within a shared, collaborative setting.

The main motivation for this experience is based on several reasons: a) personal passion for pedagogical innovation and curiosity; b) assess the students' ability to apply the studied concepts in the real world (authenticity); c) convey the usefulness of the course within the program; d) monitor student progress and provide continuous feedback during the learning process; e) using AI tool; f) to engage students in peer review practices.

The following sections focus on the formative assessment features (section 2), the methodology adopted in the experiment (section 3), the findings of the experience, based on the analysis of students' perceptions of the approach (section 4), and the conclusions (section 5).

2 Formative assessment

Formative tests aim to track student progress, offer timely feedback, and foster learning development, prioritizing growth over mere performance evaluation. Unlike summative assessments, they emphasize ongoing improvement rather than delivering a final judgment (Black & Wiliam, 1998). Formative assessments help identify students' strengths and weaknesses, allowing both learners and educators to adjust their approaches accordingly (Sadler, 1989). They serve as a diagnostic tool, helping instructors tailor their teaching strategies based on student performance. In contrast to summative assessments, which commonly contribute to final grades, formative tests are generally low-stakes and have minimal impact on overall results. Anxiety among students is a significant factor contributing to low academic performance and, in many cases, to dropout. The formative test lowers student anxiety and promotes active engagement with the course in a low-risk learning environment (Nicol & Macfarlane-Dick, 2006).

Formative tests promote metacognition by encouraging students to reflect on their learning strategies. This supports self-regulated learning, where students take an active role in setting goals, monitoring their progress, and adjusting their study methods (Zimmerman, 2002).

Effective formative assessments are conducted regularly throughout the course encouraging students to actively participate in their learning rather than passively receiving information. Interactive activities such as group discussions, think-pair-share, and online polls help maintain motivation and engagement (Prince, 2004).

Providing timely and specific feedback is a core component of formative testing. Feedback should be constructive, guiding students on how to improve their understanding and performance rather than simply indicating right or wrong answers (Hattie & Timperley, 2007).

3 Methodology

The course assessment consists of two summative tests, accounting for 80% of the final grade. To complement these, two formative tests, worth 20% of the final grade, are designed to involve students in both problem formulation and resolution and in peer revision process. The class is divided into 16 teams, each composed of four students. The curriculum content of the course unit is also structured into 16 topics, each formative test cycle covers 8 topics. The process of distributing the topics among the various teams was carried out randomly by means of a draw conducted in the classroom (see 3.1).

The formative assessment process follows these steps for each formative test:

- teams propose exercises related to 8 specific topics within the course syllabus and post them on Padlet in its respective column
- other teams solve the respective exercise and post the resolution below the exercise proposal on Padlet
- the review of the exercise solution is conducted by the team that proposed it and is likewise uploaded to Padlet.

In the second formative test, the teams exchange roles. Specifically, the team that solved the exercises in the first formative test will now propose and review the exercise solution. To make this task easier, the exercise solutions could be handwritten.

The Padlet (Figure 1) is organized into columns, each assigned to a team. Every column is headed by the team's designated number, names and a photo of its four members. A Padlet platform is used to facilitate collaboration, storing all proposed exercises, solutions, and evaluations. The availability of the entire process on Padlet fosters the learning of all students, while also encouraging them to propose engaging exercises. This structured approach fosters student involvement, cooperation, and knowledge construction. The formative test is developed progressively over the course of the semester, in parallel with the delivery of the course content.

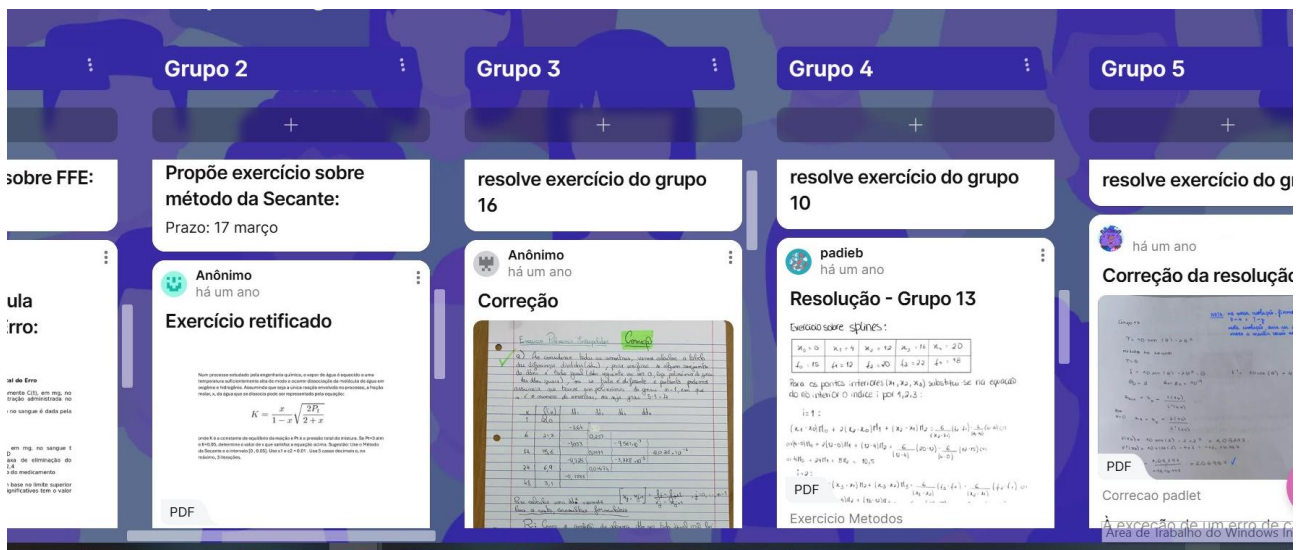


Figure 1. Padlet (<https://padlet.com/teresamonteiro/terete/alunos-aprendizagem-ativa-4-valores-rjljdud435ra57g>)

3.1 Distribution (subjects and roles)

The syllabus of the course unit (Numerical Methods) is structured into 16 subjects (Table 1).

Table 1. Subjects of the course

#	Subject
1	Fundamental Formula of Error
2	1 Nonlinear Equation – Newton's Method
3	1 Nonlinear Equation – Secant Method
4	Nonlinear System
5	Gauss-Seidel Method
6	Newton Interpolating Polynomial
7	Identify if it is a spline
8	Build Cubic Spline
9	Numerical Integration (data in table)
10	Numerical Integration (function)
11	Least Squares (polynomial model)
12	Least Squares (non-polynomial model)
13	1st Order Differential Equation (initial condition)
14	1st Order System of Differential Equations (initial condition)
15	Higher Order Differential Equation (initial condition)
16	Differential Equation (boundary condition)

Each team takes on two distinct roles: in one formative test, it is responsible for proposing an exercise and evaluating its solution; in the other, it solves an exercise proposed by a different team (Table 2).

Table 2. Allocation of tasks and topics among teams

First formative test			Second Formative test		
Problem setting-group (1..8)	Subject (1..8)	Problem solving-group (9..16)	Problem setting-group (9..16)	Subject (9..16)	Problem solving-group (1..8)
1	1	11	9	11	5
2	3	14	10	12	4
3	6	15	11	13	1
4	8	9	12	15	8
5	2	12	13	16	2
6	7	10	14	9	7
7	4	16	15	14	6
8	5	13	16	10	3

The task of finding a real-world example in which a course concept could be applied was made easier by using the artificial intelligence tool. The proposed exercises focus on topics of great relevance in Biomedical Engineering such as: concentration of drugs in the blood, chemical engineering, administration of morphine in post-operative pain management, meteorology, prosthetics, growth of bacterial cultures, drug diffusion in biological tissues, glucose concentration in a diabetic patient, reactors.

4 Results

The task of proposing the exercise and performing the correction was worth 60% (2.4 points) and took into account the following four assessment criteria: interesting/creative (10%), well formulated (30%), appropriate to the topic (10%) and review (10%). The task of solving the exercise was worth 40% (1.6 points) and was assessed based on two criteria: correctness of the solution (30%) and whether all steps were clearly detailed (10%). For each of the six criteria, a score was assigned on a scale from 1 to 4, with 4 being the highest value.

The results obtained by the teams in this experiment are shown in the Table 3.

Table 3. Team scores (teacher's assessment)

Team	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Grade(1..4)	4	4	3.2	2.95	4	2	4	3.45	4	4	4	4	4	4	2.8	2.4

Ten of the sixteen teams (62.5%) obtained the maximum score 4 (Table 3). All members of the same team were graded equally. In a future experiment, it is intended that team members will assess their colleagues using a predefined evaluation scheme, in order to ensure a fairer assessment that reflects each member's level of cooperation.

4.1 Students' perceptions

In order to evaluate this pedagogical experience by the students side, a questionnaire was made available on Google Forms with 48 answers in 64 students. The aim was to assess the students' opinions regarding its usefulness, the promotion of authenticity (i.e., application to real-world situations), their level of autonomy, and the use of AI tools. Regarding the usefulness of the pedagogical experience, more than 77% considered it useful or very useful (Figure 2). With regard to establishing connections between the curricular unit's concepts and real-life phenomena (authenticity), the percentage was slightly higher – 81% agreed or strongly agreed (Figure 3). In order to identify the students' level of autonomy, they were asked whether they had requested support from the instructor at any stage – less than 40% did so, which indicates a reasonable degree of autonomy (Figure 4). This autonomy may be explained by the use of the artificial intelligence tool – on this point, more than 77% of the students reported having used it (Figure 5). 71% of the responding students identified the task of proposing the exercise as the most difficult one. In a previous pedagogical experience (Monteiro, Hornink & Vieira, 2021, 2022), students identified the main challenge as finding a real-world phenomenon where a concept from the curricular unit could be applied. The use of the AI tool greatly facilitated this task by helping formulate appropriate questions.

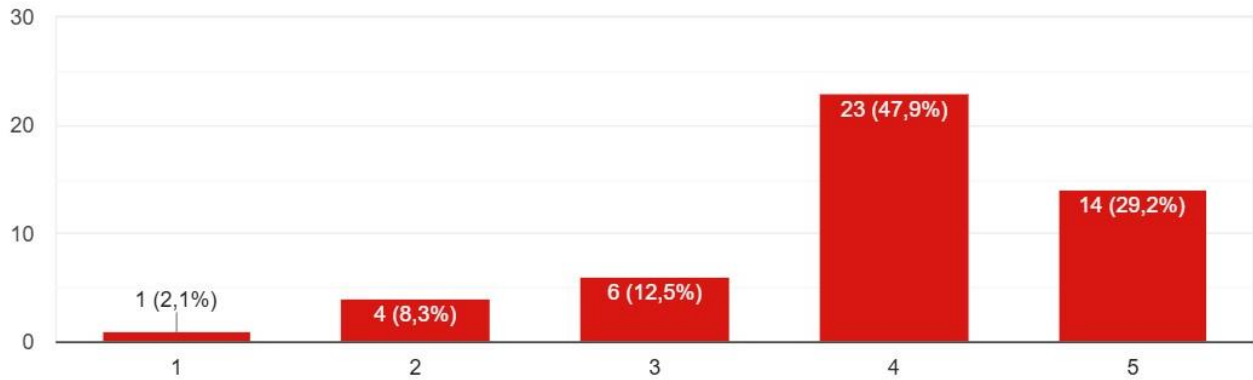


Figure 2. Usefulness in the teaching-learning process (5 – very useful)

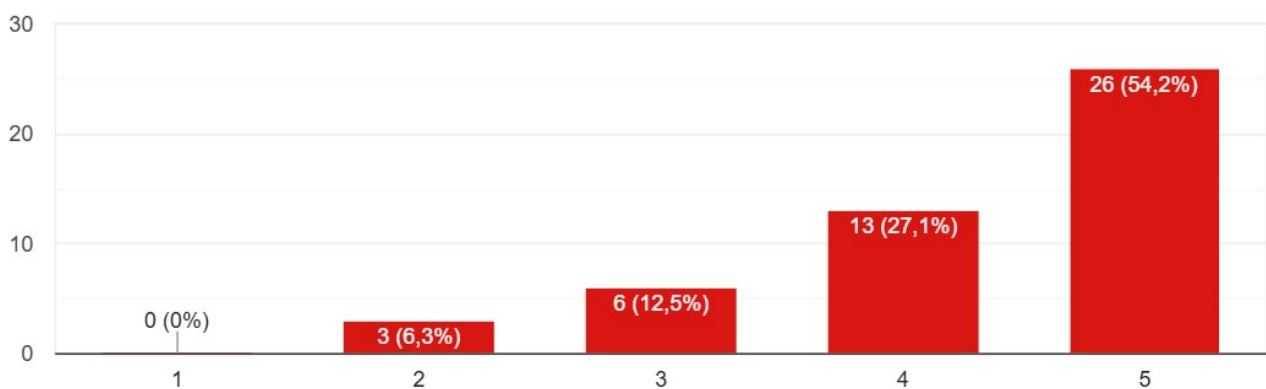


Figure 3. Linking theory to real-world practice (authenticity) (5 – very strong link)

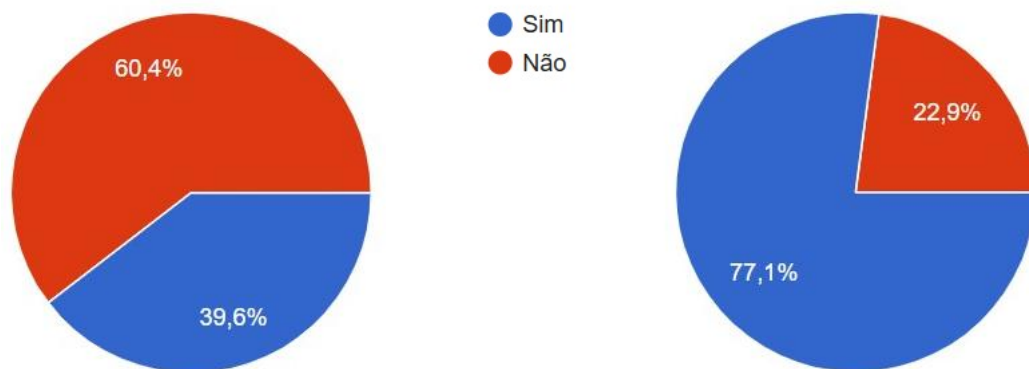


Figure 4. Need for teacher support (Sim – Yes; Não – No). Figure 5. Use of artificial intelligence tools

The questionnaire also included an open-ended question where students could express their opinions and possibly suggest improvements. 39 students answered the open-ended questions. Three of these responses are less positive (these students reported that they used Padlet very little during the semester) – more than 92% appreciated this pedagogical experience. Below are some of those comments exactly as they were stated:

- I really liked this form of assessment. It wasn't very complicated and was a different and effective way to consolidate the material taught in class. I wouldn't change anything.
- I liked the activity. I thought that especially the task of proposing exercises helped to better understand the subjects and prepare for the test.

- I liked it and think it should continue.
- I thought it was a good way to deepen my understanding of the subjects since it requires knowing the content in order to solve and propose exercises.
- It was great for testing our skills before each test.

There were also suggestions for improvement, such as, deadlines for the task set in advance, smaller teams, the solutions had to be approved by the teacher before being posted. These suggestions are valuable and will be taken into account in a future similar experiment.

5 Conclusion

This experience allowed students to develop critical thinking skills, promoting teamwork, creativity, authenticity, engagement, using AI tools effectively, and establishing connections with other course units. Preparing students to competently evaluate tasks is fundamental, as such skills will be central to their future professional responsibilities - this competency was fostered through the implementation of peer review.

The student feedback was positive and the teaching and learning environment in which the experience took place was very pleasant.

Acknowledgments

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Developing Scientific Female Leaders in STEM: a Road Trip of Female Mechatronics Students

Rafaela Villalpando-Hernández¹, César Vargas-Rosales¹, René J. Díaz¹

¹ Tecnológico de Monterrey, Engineering and Science School, Monterrey, México.

Email: rafaela.villalpando@tec.mx, cvargas@tec.mx, renejdm@tec.mx

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Abstract

Participation of women in STEM (Science, Technology, Engineering, and Mathematics) areas, have demonstrated to be crucial to develop a just, balanced and equitable society. In this work in progress paper, we present evidence of women inclusion in automatic control, robotics and technological based projects throughout the adequate project selection along their career progress. We worked with the challenge-based and research-based approaches, observing developing of skills such as increase of analytical analysis, complex thinking, logical thinking, innovation, collaborative work, organization and leadership.

Keywords: Women inclusion, STEM, female engineers, research-based learning, challenge-based learning.

1 Introduction

Inclusion of women in STEM areas at early ages is a crucial element in the design and development of an advanced society. This topic has become relevant in recent decades. Traditionally, STEM areas were dominated by men, leading to several society problems, such as professional gender disparities, gender barriers on STEM areas, bias in job opportunities, among others (Geetha, 2024; Jebesen, Nicoll, & Jayasinghe, 2022; Swafford, & Anderson, 2020). However, important efforts in the academic environment have been made to help to close the gender gap in STEM areas.

Academic institutions instrumented by professors, play an important role promoting the inclusion of women in STEM, throughout properly designed study plans, mentorship programs, hiring of female scientists and professors.

The inclusion of women in STEM is important for several reasons: diversity, economic empowerment, creation of role models for everyone as well as decreasing the gender gap, (Sevilla, Luengo, & Farías, 2023; Verdugo-Castro, García-Olgado, & Sanchez, 2022). In summary, the inclusion of women in STEM is not only a matter of fairness and equality, but it also leads to greater innovation, improved solutions to global challenges, and resilient economies.

The Tec21 educational model, implemented by Tecnológico de Monterrey since 2019 in its professional courses, is based on the challenge-based learning model. By solving real challenges linked to the environment, students develop disciplinary competencies (knowledge, skills, attitudes and values necessary to practice a profession) and transversal competencies (developed throughout a career, useful for the life of the graduate, with impact on the quality of their work), which are demonstrated through the evidence of learning that students must present. This educational model consists of four fundamental components: challenge-based learning, personalization, inspiring faculty and memorable experience (Modelo Educativo TEC21, 2018; Olivares, 2021).

In this work in progress paper, we show a slight view of the vocational learning process of female mechatronic students in different stages of their engineering program. We will observe how female engineer students get

involved in the design and development of technology based projects and scientific research studies, increasing their analytical and logical skills necessary skills for the new century (Dinelti, Elizar, & Ali, 2007; Herlinawati, Marwa, Ismail, Dominikus, & Situmorang, 2024), by applying their knowledge and using pedagogical tools such as challenge-based learning and research-based learning, which are learning tools promoted by the Tec21 educational model.

2 Methodology

In this section we are going to describe the road trip of female Mechatronics students throughout their engineering program experience. We had observed how throughout projects and challenges they develop different skills than their peer male students.

2.1 Bachelor of Science in Mechatronics Engineering (BME)

The BME Program in Tec21 is formulated in eight semesters and it is based on training units. A training unit can be defined as a curricular space delimited in terms of content and time that can be implemented throughout four different methods: blocks, subjects, TEC weeks and TEC semesters. Also, a professional career in Tec21 is divided into three stages: exploration, focus and specialization. During the focus phase, mechatronics students are introduced into electronics, system characterization microcontrollers, mechanics and automatic control systems among others. The average composition of the group is approximately 80% male and 20% female students. In the following sub-sections, we present several cases of technological projects developed by female students of the mechatronics degree program in different stages of their career.

2.2 Learning Process

2.2.1 Fourth semester

Students start to work with system characterization, modeling an active suspension for an automotive vehicle. The main goal is to formulate the state space model of an active suspension of a $\frac{1}{4}$ with 2-Degree of Freedom (2-DOF) and $\frac{1}{2}$ with 4-DOF automotive vehicle. See Figure 1.

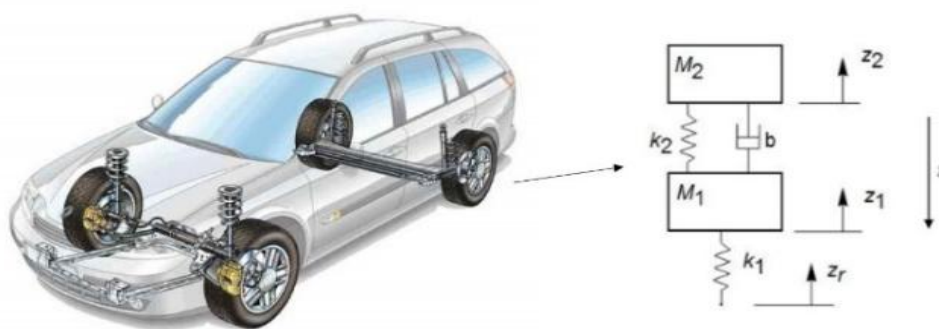


Figure 1. Vehicle suspension assessed in the project.

They work with the following methodology:

- Research commercial solutions for passive, active, and semi-active suspensions.
- Research mathematical models of passive and active, semi-active suspensions for $\frac{1}{4}$ and $\frac{1}{2}$ vehicles (reported in books and/or research articles).
- Obtain the mathematical model with differential equations for $\frac{1}{4}$ passive vehicle (2-DOF).
- Obtain the transfer functions for $\frac{1}{4}$ passive vehicle according to the outputs of interest (2-DOF).

- Through simulations, they evaluate the systems for different signal inputs.

Through this challenge, the female students developed analytical and complex thinking applying specific knowledge acquired in the subject. They demonstrated mastery of the topics covered in class, their analytical capacity, their ability to work as a team and self-management. For this challenge, it is proposed that two competencies must be achieved. Table 1 describes the competencies, and the evidence evaluated in this challenge.

Table 2. Competencies developed at a challenge reported in fourth semester.

Competencies	Description	Evidence
Fundamentals	Explains the operation of engineering systems and devices through structured and coherent arguments based on concepts, theories and principles of natural sciences, mathematics and computing.	Writing exam and oral presentation.
Integration	Appropriately applies mechanical, electronic, software and automatic control technologies taking into account specifications.	Writing report following the methodology explained above. This report includes simulation and validation.

2.2.2 Fifth semester

At this period students work on the design and develop the control systems, through out a training unit composed by, learning blocks and specific units. They work on the basis of the challenge-based learning tool. The challenge in this phase is to design and implement a mechatronic system for the automation of an industrial equipment or process. The system is implemented through the application of mechanical, electronic, software and automatic control technologies. The challenge may be linked to the manufacturing industry, the health sector or the commercial sector and will allow students to put their professional experience and personal talent at the service of others, to find solutions to economic, energy and environmental challenges through the use of technology. The following study case was developed by several students of the mechatronics program.

Students developed an automatic intensity control system for luminaires located in the university laboratory (see Figure 2); they worked with the following methodology.

- Input signal processing. 1. Place light sensors at strategic locations to monitor the available natural light. The sensors should have the capability to detect lux levels. 2. Position motion sensors at entrances or central locations to detect the presence of people in the laboratory.
- Luminaries' characterization. They obtained the mathematical representation of the actuators, by using the System Identification Tool from MATLAB.
- Control design. In basis of their knowledge acquired throughout the mechatronics program they designed and evaluated different automatic controllers for the actuator.
- They implemented the prototype and performed validation.
- Energy monitoring. They included energy metering components to monitor the energy consumption of the lighting system. This data could be used for optimization or analysis purposes.

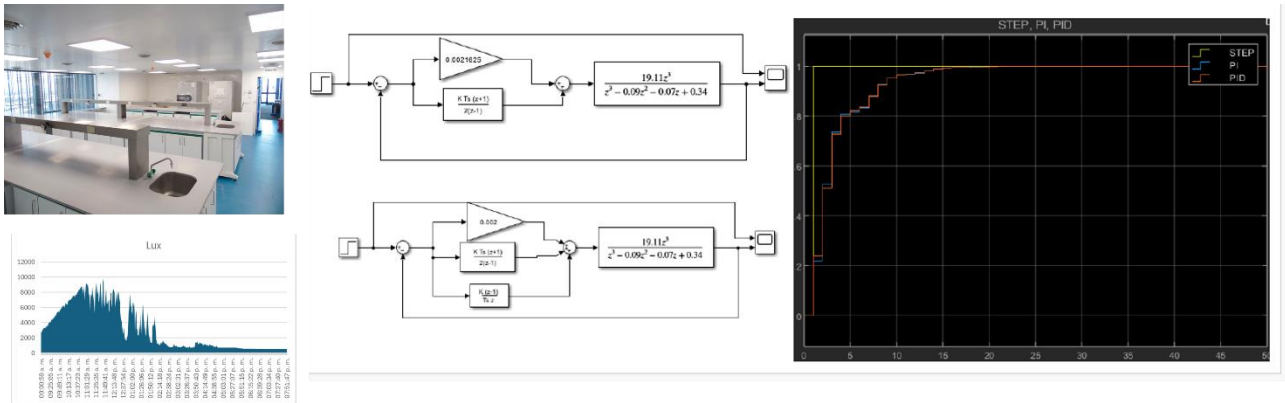


Figure 2. Automatic control of laboratory luminaries' design.

In this challenge, female students show leadership, self-learning, management, collaborative work and effective communication skills as they are capable to implement the acquired knowledge in technological based projects. For this challenge, it is proposed that two competencies must be achieved. Table 2 describes both and presents the evidence with which it will be evaluated.

Table 2. Competencies developed at a challenge reported in fifth semester.

Competencies	Description	Evidence
Process characterization and validation.	Performs theoretical and experimental modeling of dynamic systems and handles graphic identification techniques of real processes based on the step response of the system. Perform experimental tests.	A report where the students describe the system characterization process. Validate the mathematical expression obtained for the physical system, throughout simulation tools.
Logical reasoning	The student evaluates her own and her team's reasoning, based on the logical elements that give greater certainty to, statements and assumptions, in her discipline.	Oral presentations in teams.

2.2.3 Sixth semester

At this stage, students have a sufficient domain in analog and discrete automatic control, mechanics, electronics and programming. At this semester they develop the design and implementation of a four degrees of freedom robotic arm with the following specifications:

- Degrees of freedom: 4
- Links: 2
- Joints: 4
- Repeatability: 10mm
- Payload: 200gr-300gr
- Working Range: 150 mm - 400 mm
- AC 120V Power Adapter
- Control at joint level

Students design and implement all the issues related to the robotic arm, from the mechanics, electronics, actuator characterization, control and forward and inverse kinematics design, as illustrated in Figure 3.. They follow the following methodology:

- Define system requirements and restrictions
- Mechanical design. This includes, material selection, effort analysis, among others.

- Selection of components (actuators, sensors, board)
- Control System Design. This includes forward and inverse kinematics, characterization of actuators, design and evaluation of PID controllers)
- Software development
- Prototyping and assembling

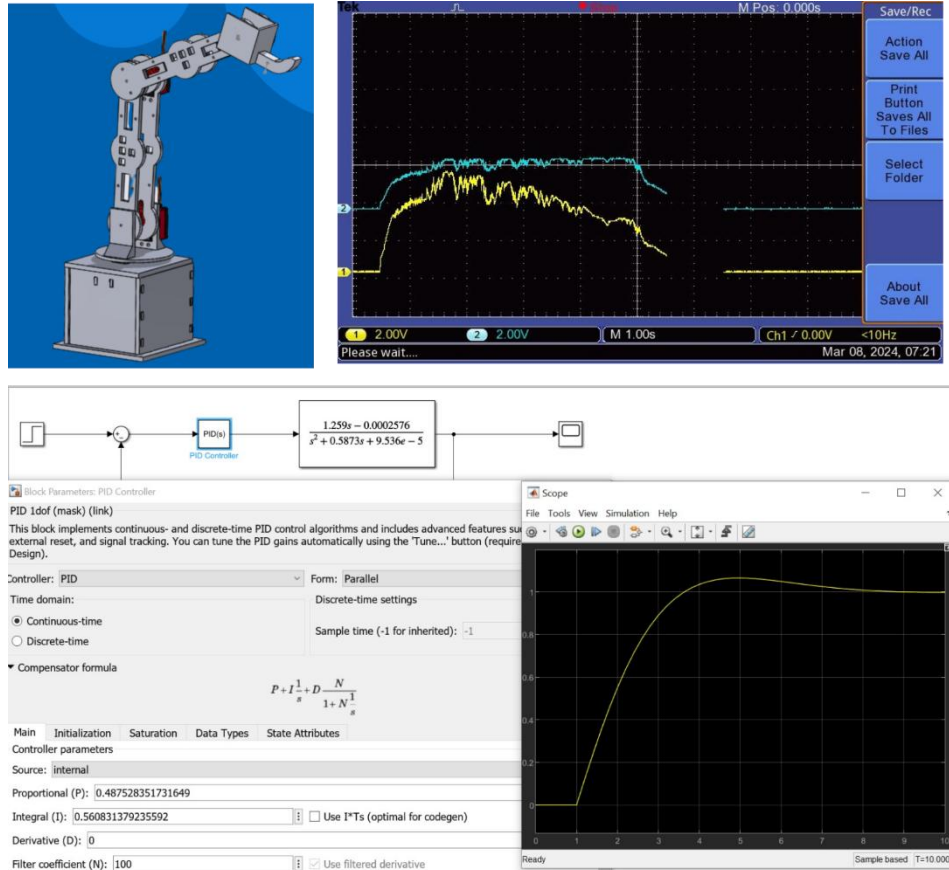


Figure 3. Design and implementation of an articulated robotic arm.

In this challenge, the students close a learning cycle in the automatic and discrete control area. They now have the tools to design, develop and integrate complex mechatronic systems. In addition to all the aforementioned skills, female students show greater abilities to integrate and lead work teams. It is also notable how the perception of their own capabilities is improved. For this challenge, it is proposed that two competencies must be achieved. Table 3 describes both and presents the evidence with which it will be evaluated.

Table 3. Competencies developed at a challenge reported in sixth semester.

Competencies	Description	Evidence
Develop mechatronic systems	Generates innovative proposals for a mechatronic system according to standards.	A report where the student reports the system design and evaluation, following the methodology explained before. The prototype
Assesses the technical and economic feasibility of a technological development.	The student is capable of evaluating the technical feasibility of a mechatronic development taking into account restrictions.	Technical report and oral presentation, where technical and economic feasibility were assessed.

3 Some differences between female and male student peers

Beside the technical competencies reported in Table 1, 2, and 3, female students have been observed to outstand on the following transversal competencies:

- Strong written and verbal communication skills for technical documentation and collaboration with team members.
- Ability to work effectively as part of a diverse team, understanding team dynamics.
- Mentoring junior engineers and take initiative on projects outside the curriculum. As we involve female students from advanced semesters as mentors of younger female students in some activities.
- Flexibility to face changing project requirements or workflows.
- Female students are prone to utilize more collaborative and consensus-driven approaches when facing problems, while male students may be more prone to individualistic solutions.
- Female students may adopt more conciliatory approaches to solve conflicts, while men students may be more direct or confrontational in their methods.

4 Conclusions

In this work in progress paper, we presented a slight view of the path of female students of the Bachelor of Science in Mechatronics Engineering (BME) program in the Tec de Monterrey. We placed special emphasis on the process of developing skills and competencies of female students, since the participation of women in STEM areas is crucial for the development of just and equitable societies. Where we also benefit as a society from the characteristics of female engineers, such as empathy, responsibility, inclusion and leadership that will lead us to a technological platform with greater innovation and development for everyone.

Acknowledgments

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Engaging More Widely in Design Projects for Engineering Students. Student Reflections on Their Experience with Stakeholder Interaction and Empathic Imagination Tasks

Jan Van Maele¹, Diana Bairaktarova², Veerle Bloemen¹, Inês Direito^{3,4}

¹ KU Leuven, Faculty of Engineering Technology, Leuven, Belgium

² Virginia Tech, College of Engineering, Blacksburg, USA

³ University of Aveiro, TEMA, Aveiro, Portugal

⁴ University College London, CEE, London, UK

Email: jan.vanmaele@kuleuven.be, dibairak@vt.edu, veerle.bloemen@kuleuven.be, ines.direito@ua.pt

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Abstract

In this qualitative, exploratory study we analyze the reflections of engineering students after participating in a design-based team project course in biomedical engineering at master degree level at a European university. By gaining insights into how students experience a combination of real-world stakeholder engagement and empathic imagination tasks, the authors seek to inform novel approaches to fostering active, empathy-driven learning environments in engineering education. The design-based team project course aims at developing students' professional competences for addressing 'wicked' problems through active learning at iterative stages of the design process. Students are invited to engage with a wider circle of stakeholders beyond technical experts to ensure project outcomes that take the broader societal context into consideration. To this end a set of active learning tasks were developed for empathic imagination of stakeholder needs and viewpoints to complement the actual interaction with stakeholder group representatives. Data on student perspectives were collected through written end-of-project reflections of all the enrolled students (N=18). This paper analyzes the ways in which the learning tasks for stakeholder interaction and empathic imagination have impacted the student experience. Inductive coding of the data revealed eight themes, revealing students' general unfamiliarity with open projects centered on real-world problems; their understanding of the importance of communication skills and empathy; and their appreciation of the value of perspective taking through empathic imagination tasks and repeated direct interaction with stakeholders, who bring new insights that will ultimately lead to improved solutions. On the basis of the study, it can tentatively be concluded that by embedding real-world challenges, sustained stakeholder engagement, empathic imagination tasks, and iterative opportunities for feedback into the curriculum, educators can better prepare students to address the complexities of modern engineering with both technical excellence and a sensitivity that reaches out to all sentient beings.

Keywords: Design Project, Empathy, Stakeholder Engagement, Student Reflections.

1 Background and Rationale

The integration of empathy-building practices into engineering education has increasingly been recognized as critical for preparing students to tackle complex, human-centered challenges (Bairaktarova, 2022; Davis, 2018; Walther, Miller, & Sochacka, 2017). Wicked problems (Buchanan, 1992), characterized by their complexity, uncertainty, and the need for stakeholder-driven solutions, demand that future engineers engage in sustained perspective-taking and empathetic imagination (Rittel & Webber, 1973; McGowan & Settelmaier, 2022). Design thinking frameworks, especially those involving real-world stakeholders, provide a natural opportunity to nurture empathy within team-based environments (Brown, 2009; Johansson-Sköldberg et al., 2013). With respect to nurturing empathy, a growing body of research suggests that perspective-taking activities asking students to step into the experiences of others can foster deeper understanding, collaboration, and more socially responsive solutions (Liedtka, 2015). In higher education broadly, perspective-taking exercises have been shown to promote openness, critical thinking, and ethical awareness, especially when activities are carefully scaffolded, involve authentic interaction, and offer students opportunities for sustained

reflection (Gehlbach, 2004; Gehlbach, Brinkworth & Wang, 2012). Studies across higher education contexts have shown that experiential and perspective-taking activities can significantly enhance students' empathy, problem-solving abilities, and engagement (Eyler, 2009; O'Connell & Dymont, 2016). Wicked problems can serve here as a creative sensitizing tool because they call for a multi-perspectival approach (Lönngren et al., 2016). Effective empathy-focused interventions in higher education typically demand repeated exposure to diverse perspectives, opportunities for iteration and feedback, and intentional support in developing communication and reflective skills. Empathic imagination tasks (Van Maele et al, forthcoming; Walter & Sochacka, forthcoming; Zaki & Ochsner, 2012), which encourage students to mentally simulate the experiences of diverse users affected by engineering decisions, are a promising set of perspective-taking activities to complement engagement with real-world stakeholders. Integrating these activities within an experiential learning educational practice, in which students learn through direct experience and reflection, is essential for developing competencies needed to navigate complex real-world challenges (Kolb, 1984; Eyler, 2009). Building on this foundation, the current exploratory study explores how students experience real-world stakeholder engagement and empathic imagination tasks in a design team project, and how these experiences can inform approaches to fostering active, empathy-driven learning environments in engineering education.

2 Educational Context and Research Method

The current paper is part of a larger study into the potential of active and student-centered approaches, such as PBL (problem- and project-based learning), in promoting empathy development in engineering students (see Bairaktarova et al, 2024, for information on the educational contexts of the wider study). The setting of the current study is a design-based team project course for master students in biochemical engineering with a biomedical focus at a comprehensive university in Europe. This course is taught by the first and third author of this paper. The project revolves around a real-world problem introduced by a civil society stakeholder, who acts as the commissioner of the project. In this case, the manager of a horse owners' association raised grave concerns about an equine chronic liver disease that is assumedly caused by ragwort poisoning and asked the students to come up with solutions. Students worked in teams of three or four during seven full-day sessions spread out over the semester following an iterative design cycle. The approach to developing empathy was implicit in that the instructors did not mention this concept when they introduced the tasks that require empathizing on the part of the students to bring the task to a fruitful end. Instead, the various learning activities were presented as ways for students to better understand and interact with key stakeholders of the issue at hand so as to arrive at more effective designs. After identifying, analysing, mapping and prioritizing all stakeholders involved, the students developed personas for each stakeholder group, gaining an insider ('emic') understanding of how the issue at hand can impact individual members. This phase of the course encouraged teams to consider the issue from multiple perspectives before converging on their specific problem statement. This initiated a new ideation phase in which each team thought up multiple approaches for addressing the problem by putting themselves in the stakeholders' shoes, using empathic imagination tasks such as voicing personas and figure storming, in which students brainstorm from the perspective of a stakeholder persona. After selecting their specific design objectives, students created low-fidelity prototypes of their tangible solutions. Through user feedback, stakeholder interactions and cross-team discussions, students were given the opportunity to assess their initial prototype and (re-)create a modified version. In the final session of the course, students presented their solutions to invited stakeholder representatives and engaged once more in dialogue with them.

This paper presents the results of a qualitative, exploratory study that was carried out to gain more insight into how students look back on the stakeholder activities they engaged in during the design project. The primary

data source was a final course assignment, namely a reflection report of approximately 1,000 words in response to several prompts, asking about the student's experiences of engaging with the stakeholders, the emotions they experienced during the course, what they found important about the course and what they would do if there were more time available. All reports were coded inductively by the first author following a thematic analysis protocol (Braun & Clark, 2006). The coding results presented below are limited to student statements related to stakeholder interaction, the focus of the current paper. All eighteen students who participated in the course submitted the assignment and gave their consent for analyzing and reporting their work in pseudonymized form. Instructors were not aware of which students had provided approval until after submission of the course grades. Ethical approval and data privacy clearance was sought and obtained from the regulatory university committee (G-2024-7840).

3 Results

A total of 148 segments were coded in the final written reflections, representing all students in the course (N=18) pseudonymized with the initials EA, EB, ... to ER. From these codes emerged eight themes (Table 1).

Table 3. Codes and themes.

Codes	Themes	Frequency of occurrence
First time: 'stakeholders'	'First time'	<i>9 instances</i>
First time: 'real'		
First time: 'open'		
Real problem	'Real world'	<i>18 instances</i>
Real people		
Real-world		
Required: 'communication'	'Required'	<i>22 instances</i>
Required: 'active listening'		
Required: 'affective'		
Required: 'comfort zone'		
Stakeholder activities: 'insightful'	'Empathic imagination'	<i>11 instances</i>
Stakeholder activities: 'meaningful'		
Stakeholder activities: 'affective'		
Interaction: 'prior'	'stakeholder interaction'	<i>18 instances</i>
Interaction: 'commissioner'		
Interaction: 'target users'		
Effect: 'insights'	'impact as effect'	<i>28 instances</i>
Effect: 'change'		
Effect: 'solution'		
Affect: 'meaningful'	'impact as affect'	<i>20 instances</i>
Affect: 'encouraged'		
Affect: 'worried'		
Affect: 'proud'		
More face-to-face interaction	'potential'	<i>14 instances</i>
More feedback		
Communication campaign		

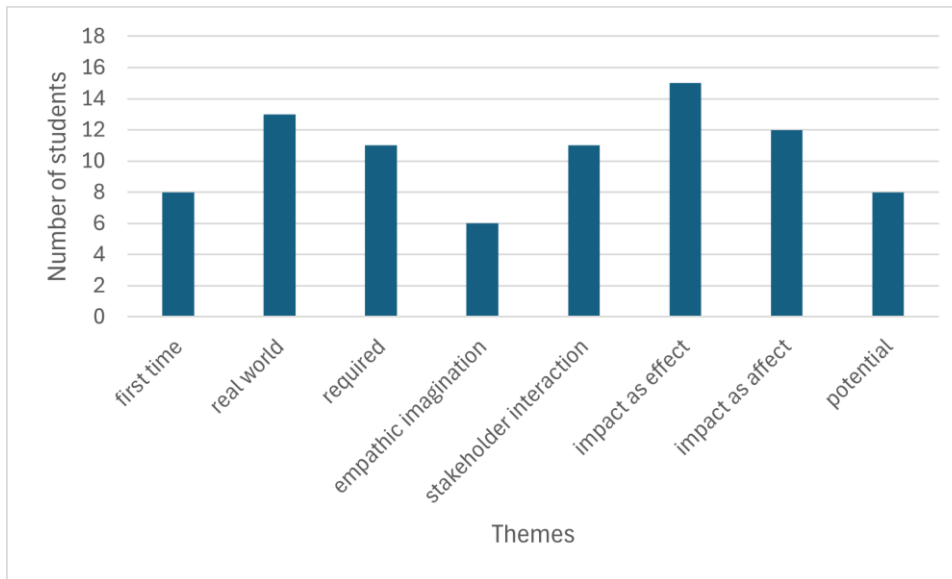


Figure 1. Student representation per theme

Figure 1 shows how many students out of eighteen contributed to each theme through one or more coded segments. The eight themes will now be introduced in the following five sections:

1. Qualifications of the project, comprising the themes 'first time' and 'real world';
2. Perceived requirements for stakeholder interaction, covering the theme 'required';
3. Experiences of and opinions about stakeholder interaction, comprising the themes 'empathic imagination' and 'stakeholder interaction';
4. Perceived impact of interaction with stakeholders, comprising the themes 'impact as effect' and 'impact as affect';
5. Additional potential for stakeholder interaction given more time, covering the theme 'potential'.

3.1 A Real-World Project, for the First Time

There are two aspects that stand out in how students qualified the team project course. Two thirds of the students made favorable remarks about the fact that "the course was structured around a real-world problem" [ER-1]. They believed it was "important to engage in conversations with real people" [EN-2], "actual stakeholders" who "added an element of real-world relevance" [EB-12]. The advantages of this real-world quality, according to the students, point outward in that "the project had the potential to make a difference" [EO-8] with "real-world implications" [EC-7] as well as inward in that the course set up a conducive environment for "equipping us with essential real-world skills and preparing us for professional life" [EA-3]. One student dissented, arguing that the lack of scientific data about horse casualties as a result of ragwort consumption "indicates that it is not a very relevant problem" [EP-1].

The other qualification many students (8/18) attributed to the course was its novelty in the engineering curriculum: "It was the first time in my engineering degree that I had to find a solution to a problem that was real and involved real people" [EB-4]. Overlooking prior experiences, a student points out that "in previous projects, we focused solely on identifying problems and proposing solutions, without considering the stakeholders' perspectives" [EB-3]. "To interact with the people for who [sic] we would develop our prototypes", another student confirms, 'was something that we never had to do" [EL-2]. The open nature of the project was something the students clearly appreciated: "Unlike previous projects with more rigid guidelines, we could explore various avenues and engage with stakeholders to develop meaningful solutions" [EF-2]. This was the

case even though the novelty of the stakeholder activities “overwhelmed” one student as they “grappled with the unfamiliar task of reflecting on our work from an external perspective” [EI-7].

3.2 Perceived Requirements for Interacting With Stakeholders

When students reflected on what is required for effective stakeholder interaction, they most frequently referred to the quality of their communication [12/22 codes]. Communication needs to be clear, detailed and precise in order to raise stakeholder interest and lead to useful feedback. “It was also crucial to frame our questions in non-scientific terms to ensure clear communication and understanding”, one student reports [EG-5]. Another student recommends a communication strategy with “a clear narrative that would resonate” [ED-8]. In addition, several students mention active listening as an “essential” element: “We need to actively listen to users’ feedback, questions, and concerns to understand their perspectives and needs” [EH-7]. Tending to the stakeholders also extends to the written mode by “adjusting our writing style to be more empathetic and attentive” [EK-8]. Indeed, for several students the application of communication techniques go hand in hand with affective aspects. In addition to adopt an empathetic and attentive attitude, students found it was important to “approach potential users with enthusiasm and confidence” [EH-2], “to build their trust by being respectful” [EE-6], and to “maintain an open-minded approach and to take on board any constructive feedback that was offered” [EE-2]. Stakeholder interactions, one student remarks, “require us to be more authentic” [EK-9] and “demonstrate a genuine interest” [EK-7]. To put these required attitudes into practice can demand a considerable effort. As two students noted, interacting with unfamiliar stakeholders can feel “daunting” and requires stepping out of one’s comfort zone [ER-3, EC-3].

3.3 Experiences of Stakeholder Interaction

One third of the students (6/18) referred to their experiences with the empathic imagination tasks in their final reflections. As explained above, these tasks required students to venture beyond familiar perspectives on the problem at hand. One student team developed a persona for the equine stakeholder group and impersonated the voice of a horse. This was “a funny and engaging experience” [ER-6], one team member explains: even though “giving the horse a human voice was unusual for a master class”, “thinking about its life, wants, and needs provided concrete insights into what the stakeholder, the horse, would desire” [ER-7]. The created stakeholders personas also served as complementary perspectives in the figure storming activity, something that was appreciated as “crucial because it’s easy to lose sight of our goals and the people we aim to help” [EK-2]. On the whole, students who commented on the empathic imagination tasks found them meaningful, valuable, and insightful. As one student explains: “I found that the persona actually provided a surprising amount of information. It allows you to view the problem from a perspective you wouldn’t initially consider and learn to see the problem from more than one angle” [EQ-2].

Approximately two thirds of the students (11/18) articulated experiences and opinions regarding their interaction with actual stakeholder representatives, excluding any reflections on the impact of those experiences, which will be reported in the next paragraph. Three students mention how prior familiarity with certain stakeholder groups proved useful for the project: “Having been around horses since I was young, I’ve developed a deep connection with these animals” [EM-2]. There was widespread appreciation for the fact that there was repeated interaction with the real-life commissioner of the project. This person introduced the project during the first session, assessed the outputs at the end, and remained available during the project term, as one student attests: “we can evaluate the effectiveness of our project by talking to our client [...] after some time and asking if he sees improvements with his initial problem” [EQ-1]. Several students reflected on why specific stakeholder interactions did not have the desired effect. They attributed this to factors such as the choice of channel (“One of the problems with interacting with the user was communication, for example in

Reddit", EO-5), the limited number of representative target users that were consulted ("we only had feedback from two or three users. So, it is very dangerous to say that the entire audience group is represented", EL-4), or differences in expectations ("I think this because of the expectations that the users have, as they expect fast answers that can be implemented now, meanwhile, the solutions we provided still focused on a research stage", EO-4).

3.4 Perceived Impact of Interacting with Stakeholders

The description and assessment of the impact of their interaction with stakeholders constitutes the largest set of coded segments in the final reflection reports. The general message that emerges is that interacting with actual stakeholders brings new insights that require changes, ultimately leading to improved solutions. One student reports they "gained valuable insights from these discussions, which helped us fine-tune our prototypes to better meet user needs" [EK-6]. Another student describes the experienced effects in the following manner.

During the process of this project, we had interactions with real stakeholders that completely changed our vision and the solution we had in mind. If these interactions had not taken place, our point of view would not have changed, and we would have proposed a solution that had already been imagined or that was not feasible. [EB-5]

No fewer than 15 out of 18 students articulated this idea in some form or other. Firstly, new insights were gathered at the earlier stages of defining the problem. Students note that thanks to interaction with a "diverse group of people from different backgrounds" they acquired a "clearer idea" of the situation [EN-3] and gained insights into its "potential consequences" [EM-6]. Additional insights were gathered during the development of the solution, for instance with respect to "user's motivations and preferences" [EH-5] and "budget considerations" [EI-5]. Students report how these new insights "often forced us to rethink and adjust our initial ideas" [EB-14] and were instrumental in putting them "back on track" [EN-6] towards developing effective and user-friendly solutions.

Stakeholder interaction did not only lead to more effective solutions, it also impacted the affective realm. At least five students remark how these interactions rendered the project more meaningful to them at a personal level. Thanks to interpersonal communication, the problem was no longer "a simple statement or research goal to tackle which felt far away from my reality, it was rather a closer problem that could almost be felt as part of my reality" [EO-1]. Another student explains the affective impact as follows: "Our users could see that we were truly invested in addressing their concerns, which in turn made us more confident and committed to our work" [EK-11]. Several students point out how "positive feedback" from the target users about proposed pathways and low-fi prototypes in the course of the project served as a validation and "encouraged me to proceed further" [EJ-3]. At the same time, the real-world nature of the project also added a level of stress for some students who experienced "being worried [...] the fear that our project might not meet the stakeholders' expectations or achieve the desired impact on the community" [ED-7]. Yet, when students experienced appreciation from the stakeholders, they note this gave rise to a keen sense of pride: "We also clearly saw how his face lit up as we were explaining our idea. This made me feel very proud as it gave me confirmation that we were successful in meeting his needs and expectations" [EF-7].

3.5 Additional Potential for Stakeholder Interaction

Approximately half the students (8/18) also reflected on what they would do additionally with respect to stakeholder interaction if there were more time for conducting this team project. A handful of students explicitly mention they would invest more time in face-to-face interactions with stakeholders. As one student notes, "they often lead to more nuanced conversations and deeper connections. However, due to a lack of time

outside the project hours, I talked with them online” [EE-1]. In one way or another all reflections refer to establishing “additional connections with stakeholders” [EA-5], be it by way of more user testing, more collaboration, or more feedback. One student explicitly states these interactions take precedence over additional literature review “to increase the depth of our research [...] because I think we found enough from literature to get a good view” [ED-3]. Furthermore, “The biggest regret in my opinion is not engaging enough with stakeholders during the prototyping phase. I think getting more feedback from our prototypes could have given us the opportunity to greatly improve the final products” [ED-4]. A couple of students mention they would make additional outreach efforts in the form of workshops or a social media campaign, for instance with the purpose of making target users “aware of the [...] benefits of the rather simple solution we propose” [EB-11]. Along with further work on the prototypes, these outreach efforts could be instrumental in creating impact: “we don’t really make a big impact during the course. Just as we could really make something the project stops. In this case we could also actually help people to solve the [...] problem” [EP-5].

4 Discussion

The findings of our study reinforce the importance of intentionally integrating empathy-building practices into engineering design education, particularly when students engage with complex, real-world problems. Students’ appreciation for working with real stakeholders, many for the first time in their college experience, highlights the power of authentic, experiential learning to create engagement that the students perceived as meaningful for their design project. This aligns with research on perspective-taking activities in higher education, which consistently show that authentic interaction and exposure to diverse experiences are key to promoting empathy, critical thinking, and ethical decision-making.

The second theme where students’ emphasize the role of clear communication for effective stakeholder engagement suggests that supporting students’ development in both technical and interpersonal competencies is critical when addressing wicked problems. Communication helps students move beyond initial assumptions and engage in genuine perspective-taking, a core requirement for empathy to have a lasting effect. Similarly, the participants’ reflections on empathic imagination tasks reveal that structured opportunities for imaginative perspective-taking can deepen students’ awareness of stakeholder needs and values, particularly when scaffolded throughout the project. Perspective-taking activities, when intentionally scaffolded, have been shown to deepen student learning and commitment to user-centered problem solving (Gehlbach, Brinkworth, & Wang, 2012; O’Connell & Dymont, 2016).

The finding that stakeholder interactions led to new insights and improved solutions highlights the dynamic, iterative nature of working on wicked problems. It also underscores the need for learning environments that are flexible and open to adaptation based on stakeholder feedback. By framing design projects as opportunities to address wicked problems, educators can foster students’ ability to navigate uncertainty and develop empathy through real-world, iterative experiences (Jonassen, 2014; McGowan & Settelaar, 2022). Students’ wish for more time to build relationships with stakeholders further suggests that fostering meaningful empathy requires sustained interaction, not one-off activities. These insights align closely with the stages of the design thinking framework — empathize, define, ideate, prototype, and test — where iterative learning, real-world engagement, and empathy-driven design are essential to developing effective solutions. The students’ reflections on adapting their solutions after stakeholder feedback illustrate the importance of iteration and flexibility, core principles in design thinking frameworks (Brown, 2009; Liedtka, 2015). These findings also align with research emphasizing that empathy in engineering education not only enhances user-centered design outcomes but also shapes students’ professional identities (Walther, Miller, & Sochacka, 2017). Our findings corroborate with the literature, further suggesting that integrating experiential learning with empathy-focused

activities offers a powerful pathway for developing students' abilities to engage with societal needs and complexities (Eyler, 2009; O'Connell & Dymont, 2016).

5 Conclusion

This qualitative, exploratory study into engineering students' experiences of stakeholder engagement in a project course shows that students appreciated the commissioned design project for its real-world implications and the opportunities to engage with stakeholders through actual interaction and empathic imagination tasks. Students highlighted that stakeholder engagement brought them new insights that required changes, ultimately leading to improved solutions and a sense of validation. Adjustments in their communication and an empathetic and authentic attitude were considered key to success. Collectively, these align with recent calls in engineering education to integrate human-centered design approaches that emphasize iterative engagement with stakeholders (Woolard & Carlson, 2020; Johansson-Sköldberg et al., 2013). The results suggest that in order to nurture active learning and empathy in engineering education, teachers must develop competencies in designing authentic, flexible, and reflective learning experiences. In the following step we will apply the same methodology to data collected in a design-based project team course data North American engineering college where empathy was an explicitly named focus of learning activities. This will shed further light on our tentative conclusion that by embedding real-world challenges, sustained stakeholder engagement, empathic imagination tasks, and iterative opportunities for feedback into the curriculum, educators can better prepare students to address the complexities of modern engineering with both technical excellence and a sensitivity that reaches out to all sentient beings.

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Enhancing Capstone Program Workflow: A Case Study on a Platform for Managing Academic-Industry Projects

Luciano Pereira Soares¹, Rafael Corsi Ferrão¹

¹ Insper, São Paulo, Brazil

Email: lpsoares@insper.edu.br, rafael.corsi@insper.edu.br

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Abstract

Capstone projects are widely adopted by universities around the world as a culminating assessment in bachelor's degree programs. These projects typically involve student teams tackling complex, real-world problems proposed by external stakeholders, such as companies, NGOs, or research centers. Although they offer valuable hands-on experience, managing Capstone projects can be challenging due to their multiple stages and demands. The process typically begins by identifying students' interests, followed by sourcing and selecting potential projects from external organizations. After presenting these options to students, groups must be formed based on various criteria, including academic ranking, GPA, previous experience, and individual skill sets. In this paper, we detail a web-based tool designed to streamline the management of Capstone projects at Insper, with an emphasis on project sourcing and group formation. We also discuss the technological solutions, and the challenges encountered throughout development and deployment. Furthermore, we present usage data from recent years, offering insights that may prove valuable for institutions or teams developing similar tools in the future.

Keywords: Capstone, group formation, management tool, project tracking

1 Introduction

A Capstone course typically requires students to develop a complex project in the final years of a bachelor's program, serving as a comprehensive academic and intellectual milestone that demonstrates their readiness for professional practice. They also often mark the first extensive endeavor that students embark on without the constraints of a predefined topic (Tenhunen *et al.*, 2023).

Due to the intensity and complexity of Capstone projects, students are often provided the opportunity to choose a project or topic that aligns with their interests, thereby boosting their intrinsic motivation. Additionally, certain group formation dynamics may be involved. However, this autonomy alone is insufficient to sustain engagement. Continuous assessments, whether individual or group-based, are essential throughout the project's development to maintain motivation and ensure consistent progress (Bessette, Okafor and Morkos, 2014).

Several institutions may also choose to undertake projects for external organizations to better prepare students for the job market (N and G, 2018). Securing high-quality projects that meet academic standards is a significant challenge, especially when projects are multidisciplinary and need to satisfy the requirements of multiple programs.

To ensure everything runs smoothly, groups typically have an advisor who orientates project dynamics, maintains a healthy relationship with the partner organization that proposed the project, addresses both technical and non-technical questions from students, reviews the project documentation, and frequently takes part in the assessment process (Paretti *et al.*, 2013).

Managing these aspects is highly complex, and the difficulty can quickly escalate depending on the number of students, projects, and the level of detail required in assessments. In this paper, we describe a pipeline and a platform developed to manage our specific style of Capstone projects.

This paper will focus on the stages associated with project sourcing, group formation, and project completion with the partnering organization, which correspond to capabilities 1, 2, 3, and 7 listed above.

1.1 Related Work

Due to the complexity of managing Capstone projects, both the academic community and educators have explored and developed various solutions to address specific challenges such as student planning, learning objective management, and individual evaluations. Many of these tools aim to enforce an agile methodology. For instance, the study by Umphress, Hendrix, and Cross (2002) analyzed 44 Capstone projects and concluded that "agile processes provide a bridge from ad hoc programming assignments to organized project work, and that process requires a suitable infrastructure of tools and process expertise." To facilitate the management of Capstone groups, several studies suggest using professional or custom software programs to assist in assessing and organizing teams (Olarite et al., 2014a; Fan, 2018).

Moreover, the application of tools in Capstone projects extends beyond group organization, as alternative methodologies have also been implemented and tested. Souza (2019) describes the development of a tool designed to gamify projects, while Neyem et al. (2025) propose using data extracted from Git repositories for individual evaluations and to monitor each group member's progress, providing evaluators with greater granularity. Additionally, given the challenges associated with forming groups in Capstone projects, specific tools have been developed to streamline group formation (Lan and Ginige, 2008).

Due to the inherent complexity, diverse methodologies, and unique characteristics of each Capstone project, institutions and educators have introduced integrated tools to manage the various demands more efficiently. Fan (2016) proposed a web-based tool that integrates project management and facilitates the submission of requirements by mentors, generating automated feedback for all parties involved. Similarly, Olarte et al. (2014b) introduced an integrated tool that simplifies monitoring the different phases of project development (planning, analysis, design, and production). In a comparable approach, Li et al. (2019) developed another tool that enhances feedback and phase management in IT Capstone projects. Lastly, Gan and Ouh (2020) detailed a web-based tool that supports comprehensive Capstone project management, including class and submission calendars, as well as the administration of project deliveries based on competencies and areas of interest.

2 Context

The open source tool (<https://github.com/insper-education/pfe>) was initially developed to manage Capstone projects at Insper - Brazil for computer, mechanical, and mechatronics engineering programs, and it has recently evolved to include students from the computer science program. At our institution, Capstone projects always address real-world challenges presented by external partners, such as companies, research centers, technology development organizations, or NGOs. Each project spans one semester and accommodates up to four students, who may come from different academic programs. Although, in theory, up to 200 students or more can be registered simultaneously, recent semesters have seen around 100 students working on 25 projects (Soares, 2024).

Capstone projects take place in the final years of a student's programs. In our case, for engineering students, this occurs in the second semester of the fourth year, while for computer science students, it happens in the second semester of the third year. By the time students begin their Capstone projects, they have completed all the required courses and are enrolled only in elective classes.

Students are expected to commit 24 hours per week to their Capstone projects, which typically last around four months. Each project is supervised by an advisor, a faculty member who dedicates 2 hours per week to assist the group, and is supported by a company representative with whom the students report weekly on their progress.

Evaluation methods are both individual and group-based. For individual assessments, students submit a biweekly self-report detailing their contributions and receive peer evaluations twice per project. These scores are used by the advisor to assess each student on four criteria: Technical Execution, Organization, Design, and Entrepreneurial Attitude. Group evaluations are conducted in three major phases: a preliminary report that outlines the project's objectives, followed by intermediate and final reports. The latter two are evaluated by a panel consisting of two external members (typically professors not directly involved in the project), ensuring that the group is assessed collectively using the same criteria as for all the projects

3 Process

The process begins with an initial meeting where students indicate their areas of interest, followed by planning, sourcing, and validation of project proposals from invited companies. Students then receive a list of approved projects and have the opportunity to ask questions before submitting their preferences. After groups are formed and advisors assigned, companies are notified, and official project work begins alongside academic activities. Midway and final reviews with the companies ensure progress, and the process concludes with an executive presentation and a request for publication authorization. The flow is detailed by day on Figure 1.

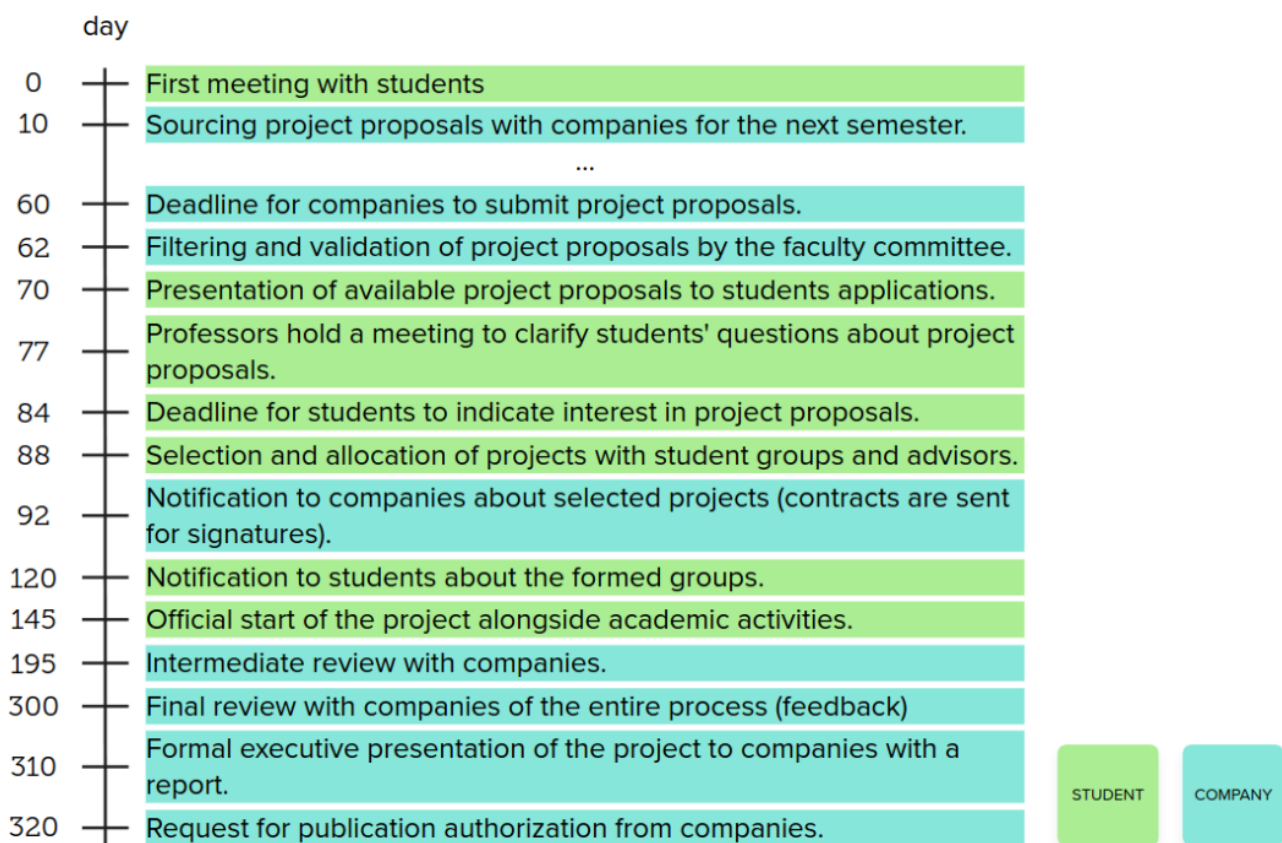


Figure 1. Capstone Project Timeline: This diagram outlines key milestones from the initial student meeting through proposal submission, project assignment, reviews, and concluding with the final executive presentation and publication authorization

3.1 Student Interests and Experiences

Once students are registered on the Capstone platform, they have access to a system that allows them to inform their areas of interest. This is one of the first actions they must take. These areas of interest will later be used to help the Capstone administration team to find projects in their preferred fields and to match the alignment between the projects chosen and their stated interests. A predefined table is provided to students, listing several areas: Computational Simulation; Industrial Automation; Embedded Systems; Data Science; Social Innovation; Interactive Systems; Information Systems; Bioengineering; Mobility Engineering; Dynamic Systems Control; Advanced Manufacturing; Administration, Economics, and Finance; Energy Efficiency; Robotics; Cloud Computing, that they have to tick. However, students are also encouraged to fill in an additional optional field if they have interests in other areas not included in the list.

In addition to selecting their areas of interest, students must answer whether they have worked, are currently working, have interned, or are currently interning at any company. This serves two purposes: first, to assess their professional experience, and second, to identify potential conflicts of interest if they are currently employed. Similarly, students are asked whether they have family members working at any company submitting a project proposal or at a direct competitor. This helps in identifying possible conflicts of interest.

Another experience-related question asks whether the student has participated in any student organizations, research programs, or other academic initiatives. This information can be used in the student selection and team formation process. Additionally, students are asked whether they have participated in social activities, such as volunteering or community work. This information is particularly relevant for projects with a social impact focus. A field for the student's LinkedIn profile is also available and can be used to review their professional background.

3.2 Organizations Outreach

Once the students' interests for the semester are known, contacts are made to partners to request project proposals. Organizations must fill out a form identifying themselves and describing their proposed project. The key fields in this form include:

- **Provisional Title of the Project:** A title that will be presented to students. This can be revised throughout the project.
- **Description of the Project:** A detailed proposal to be reviewed by professors and viewed by students.
- **Expected Results/Deliverables:** Examples include prototypes, models, tools, studies, validations, tests, or standards.
- **Resources Provided to the Student Team:** Organizations can indicate if they will provide any resources, such as development kits, raw materials, or access to cloud infrastructure (optional).
- **Other Relevant Observations:** Any additional information companies may wish to share with students (optional).

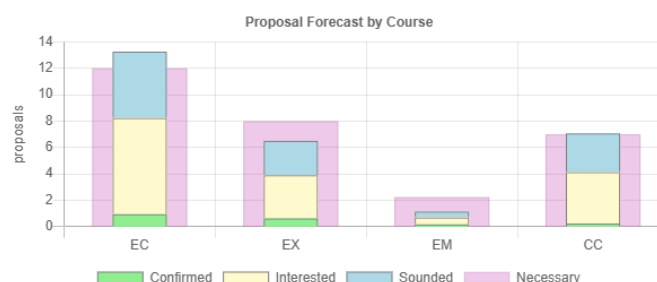


Figure 2. Graphical extract from the platform for the current semester, showing the number of students enrolled in Computer Engineering (EC), Computer Mechatronics (EX), Computer Mechanics (EM), and Computer Science. The "Necessary" box indicates the ideal number of projects required for each program.

The form also includes a section for companies to specify the areas involved in the project, similar to the student interest selection. As companies are invited to submit projects, an analysis is conducted to ensure a balanced number (neither too few nor too many). Institutions are categorized based on the types of projects they are expected to propose. Graphs, as shown in Figure 2, illustrate how the number of projects aligns with each program major.

All project proposals are stored and first evaluated by a Capstone committee composed of professors. This committee ensures that the proposed challenges meet all expected requirements, in a proposal conformity criteria:

- Does the project require knowledge and skills acquired in previous years of the undergraduate program?
- Does the project require students to apply a systematic technical design process for a system, component, or process to meet specific needs?
- Does the project represent a real-world or industry experience formally requested by an external organization?
- Does the project provide an opportunity to incorporate relevant technical standards that can be referenced in project reports?
- Does the project incorporate multiple realistic constraints, such as economic, environmental, social, political, ethical, health and safety, manufacturability, and/or sustainability considerations?
- Does the project require experimentation and hands-on skills?
- Does the project allow teamwork among students from one or more undergraduate programs?
- Is the project complexity appropriate for one academic semester (approximately 4.5 months)?
- Does the project have sufficient complexity to ensure that each team member contributes approximately 360 hours, including class time, lab work, meetings, and independent study?
- Does the project have concrete and measurable goals?

Professors also analyze each project and define the expected student profile for each major (Figure 3). For example, one project may be more suited for mechanical engineering students, while another may be better suited for computer science students. This presented information serves as a guideline, but students are free to apply to any project. However, this information is considered during the team formation phase.

Expected Student Profile

Each row represents a vacancy that should ideally be filled by a student from the marked programs

	Computer Engineering ☐	Mechatronic Engineering ☐	Mechanical Engineering ☒	Computer Science ☐
#1	☐	☐	☒	☐
#2	☐	☐	☒	☐
#3	☐	☒	☒	☐
#4	☒	☒	☒	☒

Figure 3: Professors selecting programs per student seat more suitable

If necessary, companies may be contacted to adjust their proposals, but this is often challenging when the application phase is already nearing completion. Projects that pass the conformity phase are then analyzed based on students' areas of interest. If there are project proposal gaps in certain fields, additional institutions may be contacted to submit proposals in those areas. Finally, an analysis is conducted to ensure that the

projects adequately meet student demand. Figure 4 shows how the final result is convenient for the semester with the projects required for each program major.

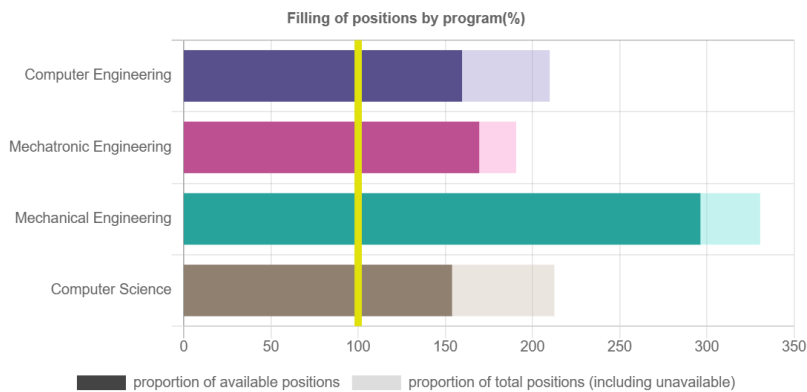


Figure 4: Each major with the approximate number of projects relative to demand. The yellow line represents 100% of the required student seats being filled. In this example, we can see that there are significantly more projects than needed to meet the required student seats.

3.3 Students Applying for Project Selection

Students must now prioritize the projects they are most interested in. In recent editions, they were required to select at least five preferred projects. They can review project details provided by companies, see which positions are recommended for their program, and check how many of their peers are interested in each project. Students have about two weeks to study the proposals and submit their applications. The image in Figure 5 shows that 7 students have already applied for this project proposal as their first option. When students see which projects are in high demand, interest tends to spread organically, simplifying the process of forming groups.

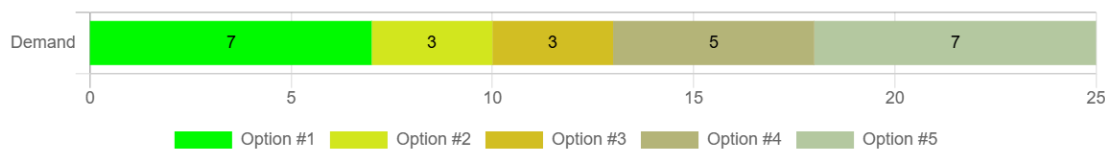


Figure 5: Example of information shows how other students are looking for a specific project

3.4 Group Formation

After students apply for projects, one of the most complex phases begins: forming the groups. Various experiments have been conducted to create the groups, but no objective function has been found that resolves all cases. Therefore, the adopted solution is to apply a heuristic that initially optimizes group formation based on the number of participants.

Groups with 2 or 3 students are prioritized since they have a higher probability of being completed with minor student adjustments. Students in groups with more than four members are analyzed to see if a redistribution can be made, moving them to groups with fewer than four members. This redistribution considers factors such as GPA and alignment of interest areas. However, the system is designed to avoid drastic changes to group compositions.

Once this phase is completed, a near-final solution is generated, typically very close to the ideal configuration for closing all groups. At this stage, students may be manually reassigned, considering more detailed information from their experience fields. Another manual step involves identifying potential conflicts of interest.

If a conflict is detected, a thorough analysis is conducted with all parties involved to determine whether the issue is significant or if it can be disregarded.

Once the groups are finalized, the process moves to the next phase, where advisors are assigned and each group must have a designated advisor. Finally, institutional partners are identified as the primary points of contact for mentorship activities and contractual matters.

3.5 Project execution

Project execution spans approximately four and a half months, guided by a faculty advisor who evaluates all interim deliverables and coordinates evaluation panels composed of two additional professors. Throughout the process, students must submit a biweekly individual report, as well as two activity reports (one individual and one group-based). For the final submission, the group—together with the advisor—can choose from three formats: a written report, a scientific paper, or a website.

Students are encouraged to meet weekly with a company representative to share progress and discuss results. However, the evaluation itself is entirely academic; the company does not take part in assigning grades. Each student receives one grade based on the group's deliverables and another reflecting their individual performance.

3.6 Project conclusion

The project concludes with the submission of a final report to the company and a formal presentation of the students' results, preferably at the company's site. Additionally, an in-person fair is held where students showcase their projects on posters; however, this event is not part of the evaluation process.

3.6.1 Overall Satisfaction

During the semester, information is also gathered from students and partners to help identify any issues with the projects. At the end of the project, main forms are distributed to both the partner organization and the students.

Questions for the partners:

Did the project progress as expected? If **YES**, do you know what the success factors were? If **NO**, can you identify the reasons? For example: delays in finalizing the scope, students not being very engaged, students having basic doubts about certain topics, or a team that wasn't fully committed.

One of the expectations for this activity was that students would gain a better understanding of the proposed challenge and discuss with you how to prototype and implement the agreed-upon solutions. Were students active in communicating, understanding your (and your end-users', if applicable) needs, and discussing possible solutions? Could you briefly comment on how these interactions went?

Was the student team allocated to your project properly organized? For example, were they punctual for meetings, did they behave appropriately, did they all dedicate themselves accordingly, and did they present an adequate proposal for conducting the project?

Do you have any other observations you would like to share with us? For example, regarding the interaction process with Inspir, or something that Inspir should have considered in this partnership proposal?

On a scale of 0 to 10, how much would you recommend the Capstone program to colleagues or partners from other companies?

Questions for the students:

1. How much would you recommend doing more projects in the upcoming semesters with the company where you worked on your project this semester?
2. Now that you know more about the company where you worked on your project this semester, would it be one of your top choices for an internship or permanent job?
3. Do you have any other comments you would like to share with us? This space is open for your observations, and we appreciate any detailed feedback you can provide.

4 Conclusion and Discussion

The Capstone program can be quite complex, involving many people from different areas. In our case, it currently includes around 20 advisor professors, 50 professors on examination boards, 100 students per semester, 100 company contacts per semester (both for project prospecting and active projects), two dedicated staff teams (one for prospecting and another for semester operations), and one main coordinator.

Over the past few years, our partner organizations have provided us with considerable feedback, consistently affirming that our projects not only meet but often exceed their expectations. With an average Net Promoter Score (NPS) of 9.45, it's clear that our partners are highly satisfied. Many are eager to submit new project proposals for the upcoming semester, whether by enhancing current initiatives or by introducing entirely innovative ideas. On the students' side, 77% strongly recommend the company, while 20% recommend it with reservations.

The tool not only provides control over all activities and ensures synchronization among all stakeholders, but it also enables the continuous improvement of the Capstone itself. Without it, managing these processes would demand significant time from everyone involved in the operation.

Additionally, this tool serves as an essential repository of academic information, helping faculty understand the impact of decisions made in a given semester. All reports are easily accessible, grades can be tracked, and various other convenient features are available. We extract data to use at ABET, ensuring that our processes meet accreditation standards while demonstrating continuous improvement in our curriculum. The system's robust analytical capabilities allow us to identify trends, assess learning outcomes, and adapt our instructional strategies accordingly. This not only supports our strategic planning and quality assurance efforts but also reinforces our commitment to academic excellence and the overall success of our students.

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EDUCADO Platform: A Learning Needs Analysis Research for Waste Pickers from Recyclable Materials Cooperatives to Support the Development of Instructional Design Courses

Marcia Longen Zindel¹, João Mello da Silva², Simone Borges S. Monteiro¹, Antônio Augusto Maciel Guimarães¹, Maria Fernanda Bastos Campani¹, Yasmim Bezerra Oliveira Altoé¹

¹ Department of Production Engineering, University of Brasília, UnB

² Graduate Program in Applied Computing, University of Brasília, UnB

Email: marcialz@unb.br; joao.mellos@gmail.com; simoneborges@unb.br; antonio.guimaraes837@gmail.com; mariafe.bastos@gmail.com; bezerrayasmim7@gmail.com.

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Abstract

Integrating waste pickers into structured educational programs is crucial for their professional and personal development. This article presents research on the learning needs analysis (LNA) of waste pickers to design instructional courses on the EDUCADO platform. LNA systematically identifies skill gaps and learning goals, enabling the development of tailored educational strategies. EDUCADO is a mobile education app developed around four key principles: project-based learning, international collaboration, sustainability, and digital solutions, applied specifically to Brazilian waste pickers. The project began at the EPIC SDG Challenge (2018), an international event featuring Aalborg University (AAU) and the University of Brasília (UnB), focused on the UN SDGs 2030 agenda. Now part of the Erasmus+ Egalitarian Project, it fosters student-driven problem-solving across universities in Denmark, Brazil, Portugal, and the Netherlands, promoting digital and sustainable solutions for waste management and social inclusion. Data collection involved semi-structured interviews conducted by students and supervisors from UnB's Production Systems Projects 2 course. Findings revealed that most participants are single mothers, solely responsible for their families, with low education levels but high interest in training—especially in hygiene and workplace safety, personal finance, basic literacy, mathematics, and digital technologies. The research underscores the need for context-aware educational programs that address the specific realities of waste pickers. Participants exhibited strong engagement and a desire to expand their skills. Future steps include new courses aligned with evolving needs and additional workshops to enhance competencies. This initiative highlights the significance of inclusive educational strategies in empowering marginalized workers and fostering their socio-economic stability.

Keywords: Waste Pickers Education, Sustainability, Instructional Design, Egalitarian

1 Introduction

Global complex challenges are intensifying, and the engineering programs are being called upon not just to produce technically proficient graduates, but ethically responsible, socially engaged, and sustainability-oriented professionals. According to the American Society for Engineering Education (ASEE, 2023) embedding societal context and sustainability into engineering curricula is no longer optional—it is imperative.

In this context, there is a demand for pedagogical strategies that move beyond traditional didactic methods. Problem-Oriented Project-Based Learning (POPBL) a pedagogical methodology that integrates the core philosophies of Problem-Based Learning (PBL) and Project-Based Learning (PjBL) have emerged as powerful educational approach that blend technical learning with real-world impact. In POPBL, students are organized into teams that engage with real-world or simulated problems, develop project deliverables, and undergo formative and summative assessments guided by supervisors. According to Berggren et al. (2021) Project-Oriented Problem-Based Learning (POPBL) is more than a teaching strategy—it is a philosophy of engineering education aligned with the realities of a complex, interconnected world. A longitudinal study by Savage and Chen (2023) reported that POPBL alumni were more successful in multidisciplinary teams and in leadership roles during their early careers.

This article presents a Learning Needs Analysis Research for Waste Pickers from Recyclable Materials Cooperatives to Support the Development of Instructional Design Courses to the EDUCADO platform. A LNA enables developers to understand the digital literacy level, and help to design user-friendly interfaces, inclusive UX/UI, and scaffolder learning experiences that account for these limitations. An LNA sheds light on the temporal and motivational patterns of waste pickers, enabling the creation of bite-sized, flexible learning units optimized for mobile learning formats (Kukulska-Hulme, 2022).

EDUCADO is a mobile education app developed around four key principles: project-based learning, international collaboration, sustainability, and digital solutions, applied specifically to Brazilian waste pickers. The project began at the EPIC SDG Challenge (2018) an international event featuring Aalborg University (AAU) and the University of Brasília (UnB), focused on the UN SDGs 2030 agenda. Now it is part of the Erasmus+ Egalitarian Project, that fosters student-driven problem-solving across universities in Denmark, Brazil, Portugal, and the Netherlands, promoting digital and sustainable solutions for waste management and social inclusion.

2 Theoretical Framework

Egalitarian projects adopt the Problem-Oriented Project-Based Learning (POPBL) “an instructional approach that places learners in the center of real-life problems and requires them to plan, design, and execute projects that propose viable solutions” (Zubaidah e al., 2020). According to Wicaksono & Prasetyo (2023) the main characteristics of POPBL are problem orientation, student-centeredness, project execution, collaboration and authenticity.

In the Egalitarian context, the Problem-Oriented Project-Based Learning (POPBL) methodology has been adapted to incorporate sustainability and digital technologies. Students work on projects related to waste management, particularly within the context of waste pickers in Brasília/Brazil, utilizing digital tools to find solutions that can be replicated in other settings. According to The Egalitarian - Good Practices Guide for Teaching and Learning (2024) the development of digital solutions is one of the core pillars of the Egalitarian project. Within the project framework, students are encouraged to apply technological tools to solve problems related to waste management and sustainability. By working in multicultural teams, participants develop innovative digital solutions that improve processes such as selective waste collection and the integration of waste pickers. These solutions are designed to be replicable, allowing the positive impact generated in Brasília to be adapted to other contexts worldwide. By integrating digitalization with sustainability, the project not only creates a positive environmental impact but also empowers students to use technology to improve the quality of life in vulnerable communities.

Waste pickers typically have limited access to formal education, digital resources, and structured training. As highlighted by Dias and Samson (2020), many waste pickers possess low levels of literacy and are often excluded from conventional adult education programs. Conducting a Learning Needs Analysis (LNA) is critical to understanding their baseline knowledge, educational gaps, and contextual learning preferences. Without such an analysis, any digital educational intervention risks being misaligned with their real needs, thus rendering it ineffective or even inaccessible. An LNA helps customize educational content to be relevant, contextually grounded, and tailored to their specific operational environment, thereby enhancing its practical application and user engagement within the app. (Schenck, C., Blaauw, D., & Viljoen, K, 2022).

According to Norman & Nielsen (2021) the success of any digital educational product from a design thinking perspective, depends on an in-depth empathic understanding of the target audience. LNA is a foundational stage in the human-centered design process. Without LNA, the educational app risks becoming a top-down intervention that fails to resonate with learners. A well-executed LNA ensures the app development follows best practices in instructional design and UX research. Understanding the digital literacy level through an LNA

enables developers to design user-friendly interfaces, inclusive UX/UI, and scaffolder learning experiences that account for these limitations. (Norman & Nielsen, 2021).

The EDUCADO Project—particularly the Learning Needs Analysis (LNA), stands out as a pedagogical and methodological innovation in the context of engineering education and digital inclusion. Its innovative nature derives not only from the product itself, a highly specific and unprecedented diagnostic tool tailored to the educational needs of waste pickers, but also from the international and interdisciplinary environment in which it was developed. The project engaged students and supervisors from multiple universities to collaboratively address a real-world challenge: designing accessible, relevant, and transformative education for a marginalized group.

A Learning Needs Analysis (LNA) for the waste pickers is relevant in the context of designing a targeted educational mobile application. A well-informed LNA uncovers opportunities to create educational modules that build environmental awareness, sustainability knowledge, and civic engagement, transforming waste pickers into active agents of environmental change. A thoughtful LNA can identify psychosocial barriers to learning and help integrate modules that valorise identity, thus increasing both participation and social inclusion. (Chikarmane, P, 2023). This research involves an innovation in inclusive digital education and a step toward achieving key sustainability goals, particularly those outlined in the UN Sustainable Development Goals (SDGs), as pointed out in the *The Sustainable Development Goals Report* (2023). The research directly contributes to multiple SDGs, particularly: SDG 4: Ensure inclusive and equitable quality education; SDG 8: Promote sustained, inclusive economic growth and decent work; SDG 11: Make cities inclusive, safe, resilient, and sustainable; SDG 12: Ensure sustainable consumption and production patterns.

3 Research Methodology

The Learning Needs Analysis Research (LNAR) was designed and conducted by the EDUCADO team from the Production Systems Projects 2 (PSP2) course at the University of Brasília (UnB) during the second semester of 2024. Firstly, the team conducted an in-depth literature review and benchmarked best practices in needs analysis applied to instructional design and ESP programs. According to Kazar and Mede (2015), a needs analysis must go beyond technical diagnostics to reveal learners' perceptions, expectations, and target skills in order to guide the development of more contextualized and effective educational strategies.

In accordance with these principles, the EDUCADO team developed a comprehensive survey, named the *Learning Needs Analysis Questionnaire for recycling cooperatives' waste pickers*, using the Google Forms tool. Indeed, it consisted of 47 questions, divided into five main theme groups; the first one related to sociodemographic profile encompasses fifteen (15) items; the second, (working conditions), seven (7) questions; the third, (professional background), two (2); the fourth, (waste pickers learning needs and gaps), nine (9); the fifth, (digital access and familiarity), twelve (12); and the sixth and last correspond of two (2) items related to the development of waste pickers personas. Inspired by the methodology employed by both Kazar & Mede (2015) and Paci (2013), the questionnaire adopted a mixed-methods design, combining quantitative items with open-ended questions to elicit both measurable data and subjective insights.

In this context, it is worth emphasizing that the personas were created using artificial intelligence tools, which generated visual representations intended to approximate the core characteristics of the target audience. These personas helped the course's content development, including audio-visual materials, illustrations, and written content. Their primary purpose was to visually represent waste pickers in a way that fosters a sense of identification, thereby enhancing the learning process through familiarity and contextual relevance.

On November 18th, 2024, the team conducted one-on-one interviews at *Recicla Mais Brasil*, a recycling cooperative located in *Paranoá*, Federal District, Brazil. Before beginning the survey, the team promptly requested verbal consent from all waste pickers of the *Recicla Mais Brasil* cooperative. Subsequently, all participants authorized the use of their data, which were recorded anonymously, aiming at protecting their privacy and, most importantly, their dignity. The data collection process occurred in person, through individual interviews, executed by the lead professor of the Educado Project, followed by two UnB students. Each interviewer read the questions aloud, applied active listening techniques, and registered the target audience's responses directly into the online form.

In total, 13 members of the *Recicla Mais Brasil* cooperative were interviewed, including leadership figures, for instance, the president and the manager. Participants should be over 18 years old and voluntarily willing to contribute to the study to participate in the interview. At the time of data collection, the cooperative had 45 registered workers. However, due to a high turnover rate—a characteristic frequently observed in informal labor environments—only approximately 30% of the workforce was present on the day of the survey. This circumstance constitutes a limitation of the study, as the final sample consisted of only 13 waste pickers. This restricted sample size underscores the necessity of expanding the dataset in future research to enhance the robustness of findings. Notably, this contextual constraint was taken into account during the sampling strategy, in accordance with the environmental analysis dimension outlined in Paci's (2013) analytical framework.

4 Results and Discussions

4.1 Sociodemographic results

According to the Learning Needs Analysis (LNA) results, 76.9% of the interviewees were women and 23.1% were men. And 38.5% of the participants were less than 30 years old, while 46.2% were over 40 years old, representing a well-distributed age profile among interviewees (Figure 1).

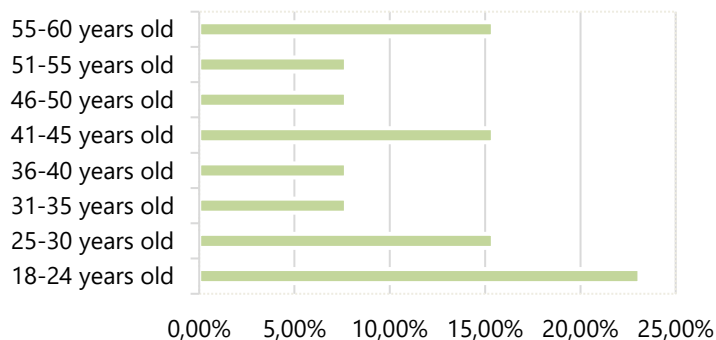


Figure 1. Interviewees' age range.

In addition, 70% of the women interviewed self-identified as Black or Brown, with 60% identifying as Brown and 10% as Black, while 30% declared themselves as white. Notably, half of the non-white female respondents were also single mothers, a reality that underscores the enduring structural inequalities that disproportionately affect racialized and gendered groups in Brazilian society (Figura 2).

According to the data presented in Table 1, 80% of the female recycling workers interviewed reported being single, and 70% identified themselves as single mothers. In 90% of these cases, the women served as the primary—and often sole—providers of their household income. Among the participants, only two women reported being married. In one instance, the spouse contributed financially to the household; in the other, the participant, aged between 55 and 60 years, bore full financial responsibility, as her husband was unemployed.

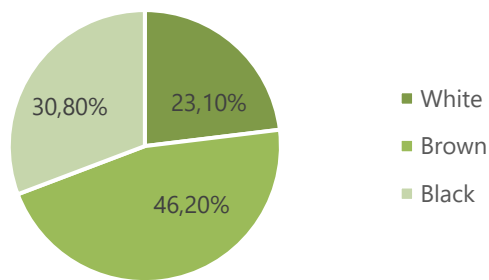


Figure 2. Skin colour - self-identification.

Similarly, 90% of the female participants reported having at least one dependent. Despite this, 70% declared monthly earnings ranging between BRL 1,413.00 and BRL 2,824.00, while 30% received less than BRL 1,000.00. A particularly striking case emerged from one participant who reported earning between BRL 500.00 - BRL 800.00 per month. This individual, a single mother aged between 55 and 60 years, was solely responsible for the financial sustenance of her household, which included six children and two additional dependents. Her maximum monthly income of BRL 800.00 was notably below the Brazilian minimum wage at the time of the LNA interviews (BRL 1,413.00), underscoring her precarious living conditions.

Table 1. Socioeconomic and demographic profile of women interviewees.

Age (years old)	Skin Colour	Civil Status	Children	House Dependents	Income (Brazilian reais)	Main Provider
51-55	Brown	Single	4	0	1413-2824	Yes
25-30	Brown	Single	4	5	1413-2.824	Yes
41-45	White	Single	5	2	1413-2824	Yes
18-24	Brown	Single	1	2	1413-2824	Yes
25-30	Black	Married	3	4	1413-2824	No
31-35	White	Single	0	1	800-1000	Yes
55-60	White	Single	6	2	500-800	Yes
36-40	Brown	Single	3	4	1413-2824	Yes
41-45	Brown	Single	4	1	1413-2824	Yes
55-60	Brown	Married	2	2	800-1000	Yes

Moreover, most interviewees lived close to their workplace, indeed, 46.15% walked to the Cooperativa, others participants resided in the adjacent neighbourhood, *Itapoã*, located next to *Paranoá*. Among them, three travelled throughout the city by motorcycles or car; two used bicycles, and one relied on the bus. All interviewees needed less than one hour to reach the cooperative, except for one outlier, who reported a commute time between one and two hours.

4.2 Education background

The participants, 46.15% reported having incomplete primary education (Grades 1-6). Additionally, 15.39% claimed incomplete lower secondary education (Grades 7-9), contrasting with another 15.39% who had completed lower secondary education. One participant indicated incomplete upper secondary education (Grades 10-12), while 15.39% - corresponding to two individuals - stated having completed high school (Grades 10-12) (Figure 3).

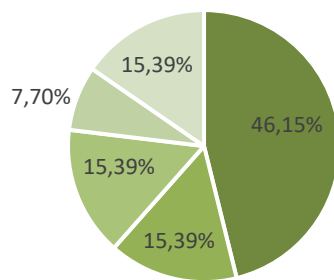


Figure 3. Educational attainment of interviewed waste pickers.

Among the six interviewees with incomplete primary education, 66.67% had interrupted their educational activities for over 20 years, whereas 16.67% had not engaged in any learning process for between 12 and 15 years. Thereafter, among the four participants with incomplete or complete lower secondary education, 50.00% was distance for between four and seven years, while the others reported academic gaps of 16 to 19 years and over two decades, respectively. Finally, among those holding a high school diploma, one claimed ongoing studies and an active pursuit of professional development, while the other remained away for over 20 years.

4.3 Economic and occupational analysis

The monthly income reported by 61.54% is between BRL 1,413 and BRL 2,824, aligned with the Brazilian minimum wage during the research period. Nonetheless, three participants earned less than BRL 1,000, two receiving between BRL 800 - BRL 1,000.00 and one outlier, BRL 500 (Figure 4).

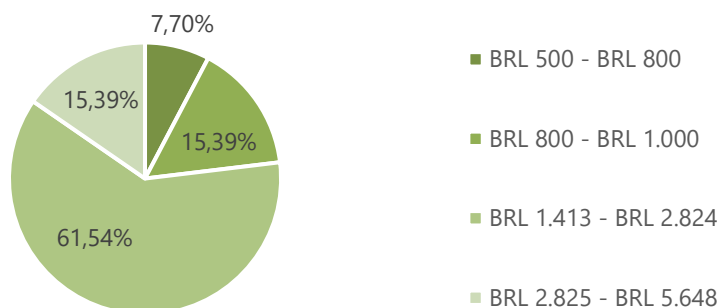


Figure 4. Family monthly income of interviewed waste pickers.

An intriguing finding was that only two out of the 13 interviewees, representing 15.39%, reported a family monthly income between BRL 2,825.00 and BRL 5,648,00. Both were men who could rely on their wives or female partners to contribute to their basic living expenses; additionally, neither had children. Among them, one held a high school diploma and continued studying, while the other, who had completed lower secondary education, had not engaged in any learning process in between four and seven years. Therefore, these findings illustrate the persisting social inequality and gender disparity, particularly in economically disadvantaged contexts. While all male participants claimed receiving support from their female partners to meet household needs, the reality for women was the opposite; indeed, they were predominantly single mothers, entirely responsible for their family finances - while their earnings remained lower than those of their male colleagues.

4.4 Learning interests

The interviewed waste pickers identified a variety of subjects they were most interested in exploring through a mobile educational platform, such as EDUCADO (Figure 5). Participants were permitted to select multiple areas of interest, reflecting the multifaceted nature of their educational needs and aspirations. The responses revealed a strong preference for content related to health, safety, and well-being (76.92%), followed by culinary skills (53.85%), personal finance (46.15%), and foundational education in literacy, handwriting, and basic mathematics (38.46%). Other areas of interest included physical activities—such as football, volleyball, and chess (30.77%)—as well as grammar, artistic expression (including music, painting, drawing, and dance), and sewing (each cited by 23.08% of respondents). Fewer participants expressed interest in crochet and embroidery (15.38%), and knitting and sales techniques (7.69%) (Figure 6). These findings underscore the heterogeneity of learning priorities within this population and point to the importance of designing mobile educational solutions that are not only accessible and flexible but also tailored to the specific socio-cultural and economic contexts of marginalized workers. Moreover, the emphasis on practical life skills and creative expression highlights the intersection of survival, personal development, and empowerment in the pursuit of educational equity.

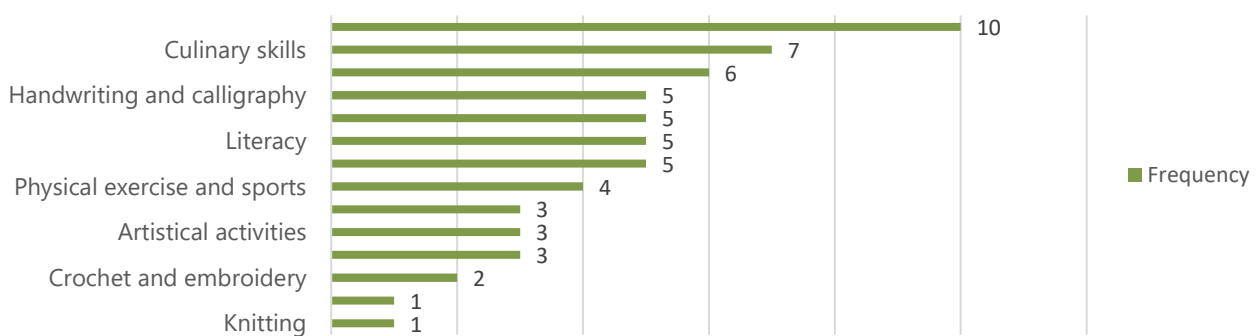


Figure 5. Learning interests of interviewed waste pickers.

Additionally, due to these findings, the group identified a common desire for continuing basic education, including mathematical concepts. As a result, the PSP2 group added one section, in the Personal Finance course, covering basic math with activities and explanations, aiming to address the target audience's needs and knowledge gaps. Among the 13 interviewees, five (38.46%) had previously participated in training related to recycling materials. Furthermore, the results revealed a strong alignment between the EDUCADO Project's course themes and the target audience's actual interests, expectations, and learning aspirations. Indeed, the two most preferred subjects from the previous data, personal finance and workplace health and safety, accurately reflected the course's content development within the EDUCADO Project.

In summary, all interviewees expressed a clear desire to continue their formal education. Notably, seven out of thirteen participants (53.85%) explicitly articulated aspirations to pursue further studies, with interests spanning from foundational literacy and foreign language acquisition to the completion of secondary education and eventual enrollment in higher education programs. Furthermore, three participants (23.10%) specifically highlighted their ambition to achieve full literacy, emphasizing the importance of acquiring effective reading and writing skills as a prerequisite for broader educational advancement.

It is worth emphasizing that, to date, no courses have been made available on the EDUCADO platform, given that it remains in the final stages of development. Nonetheless, it is important to highlight that the courses identified as priorities through the Learning Needs Assessment (LNA) will be incorporated into the platform in due course, in alignment with the strategic objectives of the initiative.

4.5 Additional income preferences

Most of interviewees, 53.8% reported having an additional source of income, in contrast to 46.2%, or six individuals, who did not. Among those in the first group, 71.43% - five out of seven - relied on government financial assistance through the *Bolsa Família* program. The remaining two, with less than six months of experience as waste pickers and notably the only participants who had effectively completed upper secondary education, pursued other activities: one man engaged in digital painting during his free time, while one woman worked as a private exam proctor on weekends.

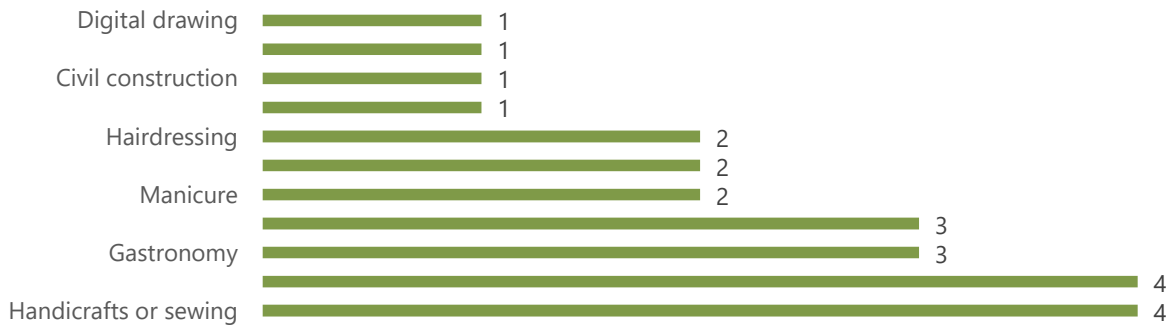


Figure 6. Additional income preferences among interviewed waste pickers.

As illustrated in Figure 6, four waste pickers expressed interest in sewing and handicraft activities, including the production of clothing and sandals using recycled materials such as PET. An equal number of participants ($n = 4$) reported entrepreneurial aspirations, with proposed ventures ranging from the sale of digital artwork to the commercialization of homemade cheese, prepared foods, and pet-related products. Additionally, three individuals demonstrated a specific interest in gastronomy, particularly in baking and cooking, while another three identified electrical services—such as installations and power system maintenance—as their preferred vocational focus. Other reported areas of interest included manicure and gel nail application ($n = 2$), domestic services such as cleaning and ironing ($n = 2$), hairdressing ($n = 2$), retail sales ($n = 1$), construction work ($n = 1$), the role of accessibility assistant ($n = 1$), and digital illustration ($n = 1$). These findings provide critical insights for the thematic planning of future training modules on the EDUCADO platform. By aligning the course offerings with the articulated needs, interests, and vocational aspirations of the target audience, the platform can enhance its relevance, accessibility, and potential for socio-economic impact.

5 Conclusion

The Learning Needs Analysis (LNA) research reveals a scenario of great social and economic vulnerability, which directly impacts the waste pickers' ability to access educational opportunities and professional development. The most educational requirements are the need for improved occupational health and safety training, handwriting and calligraphy, reading, literacy, basic mathematics and personal finance. These results show that most of waste pickers are excluded from conventional adult education programs, have low levels of literacy and limited access to formal education (Ibelli-Bianco et. al., 2022). The predominance of women among participants' points to a significant gendered dimension in the recycling labour sector, reinforcing the need for educational programs that incorporate a gender-sensitive pedagogical approach and prioritize the empowerment of female workers (Silva & Barros, 2023). Furthermore, the age distribution indicates the coexistence of distinct generational learning needs and preferences. This reinforces the necessity for multimodal instructional designs that accommodate both younger learners, often more digitally literate, and older workers who may require more analogue or hybridized approaches (OLIVEIRA et al., 2022).

In conclusion, this research underscores the transformative potential of education when tailored to marginalized communities. By engaging waste pickers as active contributors in the design and implementation of the EDUCADO platform, instructional designers can foster greater ownership, motivation and long-term retention of knowledge. This research shows that education, when designed with empathy and precision, holds the power to radically transform not only individuals but entire ecosystems of social and environmental interdependence.

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Immersive Technologies for Engineering Education: A Virtual Reality Experience at the UPTC Geology Museum.

Marien Rocio Barrera Gómez¹, Liliana Fernández Samacá¹, Andrés Leonardo Alfonso Díaz¹

¹ Universidad Pedagógica y Tecnológica de Colombia, Sogamoso, Colombia

Email: marien.barrera@uptc.edu.co, liliana.fernandez@uptc.edu.co, andres.alfonso@uptc.edu.co

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Abstract

The integration of Virtual Reality (VR) in engineering education emerges as a strategy to contribute to challenges such as accessibility, student participation, and modernization of teaching-learning methodologies. This study focuses on designing and implementing immersive virtual environments in the Geology Museum of the Universidad Pedagógica y Tecnológica de Colombia UPTC, located in Sogamoso, Boyacá—surrounded by rich evidence of geological events and heritage places. The main objective of this work is to develop dynamic and inclusive educational experiences that close youngsters and kids to geology and earth science engineering programs.

This research focuses on two main questions: How do immersive technologies impact the learning of geological and engineering issues? And how can a multidimensional design optimize the knowledge acquisition process in these fields? Using VR, exploring detailed geological models, participating in interactive educational activities, and performing virtual tours are facilitated for on-site and remote users seeking to strengthen retention and conceptual understanding.

Our project follows a methodology composed of three main stages: development, implementation, and evaluation of VR-based learning modules. The project includes the creation of immersive environments that represent geological phenomena and present engineering practices, including resource exploration, physical characteristics, and behavior of geological materials. The project is currently in its second stage, focused on refining functionality and integrating user feedback to improve interaction and learning experience.

Preliminary results suggest that VR-mediated learning environments improve the understanding of complex geological concepts while promoting the appreciation of cultural heritage. Besides enhancing the learning experience among users, the strategic implementation of VR as a pedagogical tool can potentially position the museum as a benchmark in incorporating technological innovation for promoting sustainable tourism and scientific education. Our approach aims to benefit local academic and tourist communities and to serve as a replicable model for other institutions at national and international levels.

Keywords: Virtual Reality; Geology Education; Immersive Learning; Engineering Education; Innovation.

1 Introduction

Engineering education in the 21st century faces a dual challenge: the demand for high-quality conceptual understanding and the need to adapt to the digital transformation of learning environments. Virtual Reality (VR), as part of the broader family of immersive technologies, emerges as a powerful pedagogical innovation capable of reshaping how scientific and engineering content is taught and learned. Specifically, VR introduces experiential learning opportunities that address the spatial-temporal complexities, abstract concepts, and access limitations traditionally associated with fields such as geological engineering.

A growing body of literature demonstrates that immersive technologies foster deeper engagement, enhance knowledge retention, and improve learner satisfaction (Radianti et al., 2020). These benefits are rooted in VR's ability to provide multisensory, interactive, and contextualized experiences that simulate real-world scenarios. In geology education, this capacity becomes particularly relevant, as geological phenomena often occur over vast timeframes and in environments that are difficult to access physically, such as deep-sea trenches, volcanoes, or fossil beds (Bonali et al., 2021).

The theoretical foundations of immersive learning environments stem from constructivist learning theory, which emphasizes knowledge construction through active engagement and situated cognition. VR offers a “learning-by-being” experience, allowing learners to internalize content through embodied interaction rather than passive reception (Bricken, 1991). In this sense, immersive technologies enable learners to not only visualize but also manipulate complex models, fostering metacognitive awareness and spatial reasoning skills (le Roux et al., 2021)

From a cognitive load perspective, VR has been shown to facilitate the organization of information by reducing extraneous load and enhancing germane load through interactive exploration (Mayer, 2019). This aligns with the Cognitive Theory of Multimedia Learning (CTML), which posits that learning improves when learners can integrate words and images meaningfully (Mayer, 2009). VR extends this principle by offering dynamic, manipulable 3D environments that allow for richer sensory integration and experiential cognition.

Moreover, studies on the impact of immersive virtual environments in STEM education highlight the importance of presence—the psychological sense of “being there”—in mediating learning outcomes. Makransky and Mayer (2022) argue that presence enhances motivation and curiosity, two essential elements for inquiry-based learning and scientific thinking. This motivational boost is especially critical in engineering disciplines, where abstract concepts often pose barriers to student engagement (Mayer, 2009).

Beyond cognitive gains, immersive learning environments support inclusive education by addressing accessibility issues in both geographic and cognitive terms. Learners from underserved communities, rural areas, or institutions lacking physical resources can benefit from virtual access to otherwise unreachable geological phenomena. Additionally, students with different learning preferences—visual, kinesthetic, or experiential—find in VR a platform that caters to multimodal learning (Jensen & Konradsen, 2018).

Within this pedagogical and technological landscape, the UPTC Geology Museum in Sogamoso, Boyacá, offers an ideal setting to explore how VR can transform geological and engineering education. Situated in a region of rich geological diversity, the museum acts as both a scientific repository and an educational hub. However, like many educational institutions, it faces limitations in terms of outreach, interactivity, and curriculum integration. The introduction of immersive VR experiences at the museum is intended to bridge these gaps by providing learners with interactive, context-rich simulations based on real geological data and paleontological records.

This project also aligns with global educational frameworks that emphasize the integration of digital tools to enhance quality and equity. The UNESCO (2021) Recommendation on Open Science advocates for the use of inclusive and innovative technologies to democratize access to knowledge and promote scientific citizenship. By digitizing and virtualizing geological heritage, institutions like UPTC can contribute to cultural preservation while fostering public engagement in science (UNESCO, 2021).

The present study focuses on the design, implementation, and evaluation of immersive educational modules using virtual reality (VR), with a specific emphasis on three core areas: fossils, sedimentary formations, and mineralogy. These topics were selected based on their relevance to regional heritage and their didactic potential to illustrate key geological processes. The virtual environments were developed with scientific rigor, integrating data from the Colombian Geological Survey, academic publications, and field mapping.

Two research questions guide the educational experience:

1. **How do immersive technologies impact the learning of geological and engineering issues?**
2. **How can a multidimensional design optimize the knowledge acquisition process in these fields?**

By addressing these questions, the paper aims to contribute to the theoretical and practical understanding of VR as a transformative tool in engineering education. The project's scope goes beyond technological experimentation; it is an effort to create a replicable, scalable, and inclusive model that combines scientific rigor, pedagogical innovation, and regional relevance.

In summary, this initiative integrates theoretical principles of constructivism, multimedia learning, and cognitive psychology with practical implementation in a real educational context. It seeks to validate the hypothesis that immersive technologies, when applied through a multidimensional design, can significantly enhance the learning process in complex scientific fields such as geology and engineering.

2 Methodology

This study adopted a qualitative exploratory methodology grounded in participatory and experiential learning principles to design, implement, and evaluate immersive Virtual Reality (VR) educational modules in geology and engineering contexts. The methodological framework was structured into three interrelated phases—design of immersive environments, implementation of educational modules, and impact evaluation—each developed through interdisciplinary collaboration between geology and systems engineering students, museum professionals, and university faculty. Drawing on the constructivist paradigm and experiential learning theory (Bricken, 1991; Makransky & Mayer, 2022), the project sought to foster user-centered, interactive experiences that enhance conceptual understanding and engagement. Rather than applying rigid experimental controls, the methodology emphasized authenticity, contextual relevance, and iterative refinement based on user feedback and direct observation. This approach allowed the research team to continuously adapt the technical and pedagogical elements of the VR environments to meet the needs of diverse educational audiences, including schoolchildren, university students, and museum visitors. The project also aligned with recommendations for immersive learning evaluation, prioritizing navigability, didactic effectiveness, and cognitive-emotional responses (Merchant et al., 2014; Pellas et al., 2021). Each phase of the methodology contributed to building a comprehensive understanding of how immersive technologies can support learning in geosciences while promoting interdisciplinary collaboration and the appropriation of local scientific heritage.

2.1 Design of Immersive Environments

The design phase was rooted in experiential learning principles, aiming to foster authentic, learner-centered engagement with geological content. The collaborative development team included geology students and museum staff—acting as both scientific experts and digital artists—who conceptualized the environments based on real fossil evidence. Systems engineering students then translated these proposals into immersive virtual environments using Blender for 3D modeling and Unity for interaction design.

The models were inspired by naturally occurring fossils and mineral formations found in Boyacá, Colombia. These elements were selected for their scientific relevance and cultural value, particularly specimens from regions like Villa de Leyva. Although photogrammetry and laser scanning were not used, fossil documentation and field-based sketching provided a solid foundation for accurately rendering textures, morphologies, and spatial arrangements.

Three thematic environments were developed: Fossils, Sedimentary Formations, and Mineralogy (Ruiz-Sánchez, Benavent San Cornelio, & Lázaro Calatayud, 2021). Each environment offers two levels of complexity—basic and advanced—catering to children, general audiences, and students at secondary and university levels. The design aligned with the curricular competencies of geology and systems engineering programs, while encouraging interdisciplinary collaboration. Based on these themes, three-dimensional scenarios were

developed using specialized software (Blender¹ and Unity²), incorporating real data obtained from cartography, laser scanning, and photogrammetry (Liu et al., 2017).

Interaction within these environments is primarily exploratory, allowing users to navigate at their own pace through virtual landscapes, examine artifacts, and engage with visual cues. Key features include immersive scene transitions, contextual audio guides, and intuitive controls for object manipulation. Gamified elements, such as discovery badges and knowledge pop-ups, were integrated to promote engagement without disrupting the educational flow.

The environments were also designed to be inclusive, with clear visual hierarchies and accessible navigation interfaces. This phase emphasized scientific accuracy, usability, and didactic coherence, ensuring that learners not only observe but also experience geological concepts in a virtual yet contextually grounded setting.

2.2 Implementation of Educational Modules

The educational modules were implemented using Meta Quest 2 and Quest 3 headsets, providing a fully immersive, wireless VR experience. The modules were deployed in two main contexts: structured pilot sessions with schoolchildren and an open demonstration during the "Museum's Night" academic event. In total, six groups of 15 children and one group of 20 university participants interacted with the virtual environments, offering diverse feedback for iterative improvement.

The immersive experiences were designed to support exploratory learning, allowing users to freely navigate 3D environments representing fossils, sedimentary layers, and mineralogical specimens. Though no formal tasks were assigned during the sessions, participants engaged spontaneously with the virtual content, triggering cognitive reflection and curiosity—especially among younger users. These results are consistent with findings from Merchant et al. (2014), who note that interactive VR fosters learner autonomy and deepened engagement.

Modules were built using Unity and guided by the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), focusing on accessibility, usability, and pedagogical relevance (Pellas et al., 2021). Real-time feedback from participants, especially children, highlighted aesthetic aspects—such as requests for brighter colors and enhanced environmental sounds—that contributed to improved immersion and engagement. Some students also reported dizziness, a common challenge in immersive VR that the team is currently addressing through interface adjustments.

Importantly, museum staff validated the realism and scientific accuracy of the VR representations. Their feedback ensured alignment with real fossil specimens and supported the module's credibility as an educational tool. Students noted that the VR environments facilitated a better understanding of complex processes such as fossilization, reinforcing the potential of immersive learning to enhance conceptual clarity in geoscience education (Makransky & Mayer, 2022).

2.3 Impact Evaluation

The impact of the VR modules was evaluated through participant observation and oral feedback, focusing on three key dimensions: navigability, didactic experience, and conceptual understanding. Rather than relying on formal surveys or interviews, the research team employed a qualitative approach, consistent with exploratory methodologies recommended for immersive learning environments (Merchant et al., 2014; Pellas et al., 2021).

¹ <https://www.blender.org/>

² <https://unity.com/>

Observation was conducted during both school visits and university-level sessions. In the case of university students, the experience was preceded by a traditional lecture on fossilization and geological environments. After the VR session, participants reported a deeper and faster understanding of the subject matter compared to the lecture format alone—highlighting VR’s potential to enhance cognitive efficiency and engagement, as suggested by Makransky and Mayer (2022). Students could articulate, in their own words, the physiological traits of organisms and their surrounding ecosystems, demonstrating the integration of visual and conceptual information.

Among schoolchildren, interactions were characterized by spontaneous exploration and curiosity. Children were able to identify animals, plants, and geographical features, linking virtual elements to their prior knowledge and emotional reactions. The depth of exploration and expressed enthusiasm reflected the high motivational value of the experience—an outcome aligned with findings by Radianti et al. (2020) on immersive learning’s capacity to support sustained engagement.

To systematize the observed learning outcomes, a rubric was used to assess discourse clarity and emotional association with the content. Documentation of oral reflections and behavior allowed the team to identify areas for improvement, such as enhancing visual cues and spatial orientation. This iterative feedback—particularly from the museum staff—helped refine the technical design and strengthen the pedagogical coherence of the environments.

3 Results

The implementation of immersive Virtual Reality (VR) modules at the UPTC Geology Museum yielded multifaceted outcomes across four key dimensions: iterative design advancements, user engagement and usability, contextual relevance, and cognitive gains. These results underscore the efficacy of VR as a pedagogical tool in geoscience education, aligning with contemporary research on immersive learning environments.

3.1 Iterative Design Advancements in Geological Learning

The development process of the VR modules—encompassing Fossils, Sedimentary Formations, and Mineralogy—was characterized by iterative refinement informed by interdisciplinary collaboration. Geology students and museum professionals provided scientific accuracy, while systems engineering students translated these insights into interactive 3D environments using Unity and Blender.

Initial prototypes underwent multiple revisions based on feedback from pilot sessions. Adjustments included enhancing visual fidelity, optimizing navigation controls, and integrating ambient audio to simulate real-world geological settings. These refinements aimed to create an immersive experience that facilitates experiential learning, a pedagogical approach supported by Makransky and Mayer (2022), who emphasize the importance of immersive environments in promoting deep learning through active engagement.

3.2 User Engagement and Usability Observations

User interactions with the VR modules revealed distinct engagement patterns among different age groups. Schoolchildren exhibited exploratory behavior, navigating the virtual environments with curiosity and enthusiasm. They identified various geological features and provided spontaneous feedback on aspects such as color schemes and sound effects, indicating a high level of immersion and emotional connection to the content.

University students, who had prior exposure to traditional lectures on similar topics, reported that the VR experience enhanced their understanding of complex geological processes. They noted that the immersive

nature of the modules facilitated a more intuitive grasp of concepts like fossilization and stratigraphy. This observation aligns with findings by Merchant et al. (2014), who conducted a meta-analysis demonstrating that VR-based instruction significantly improves student learning outcomes compared to traditional methods.

However, some users reported experiencing dizziness during the VR sessions, highlighting the need for careful consideration of user comfort in immersive environments. Addressing such issues is crucial for optimizing the usability of VR applications in educational settings.

3.3 Contextual Relevance and Integration of Local Heritage

The VR modules were designed to reflect the geological heritage of the Boyacá region, incorporating digital representations of local fossil specimens and geological formations. This contextualization fostered a sense of connection among users, particularly schoolchildren, who recognized familiar elements within the virtual environments.

The inclusion of region-specific content not only enhanced engagement but also facilitated the appropriation of scientific knowledge within a cultural framework. This approach aligns with the principles outlined by Radianti et al. (2020), who emphasize the importance of contextual relevance in immersive learning experiences to foster a deeper understanding and retention of information.

3.4 Cognitive Gains and Knowledge Appropriation

Observational data and oral feedback indicated that the VR modules effectively supported the development of conceptual understanding among users. Schoolchildren articulated their experiences using age-appropriate language, demonstrating an ability to relate virtual observations to real-world geological phenomena.

University students exhibited a more sophisticated discourse, employing technical terminology to describe processes such as sedimentation and fossilization. This progression in cognitive engagement underscores the potential of VR to facilitate knowledge construction across different educational levels.

Additionally, younger visitors showed notable enthusiasm while interacting with virtual representations of dinosaurs, especially local species such as *Sachicasaurus vitae* (Páramo-Fonseca et al., 2018) and *Monquirasaurus boyacensis* (Noè y Gómez-Pérez, 2022). These activities not only sparked scientific curiosity but also prompted spontaneous discussions on morphology, evolution, and the historical memory associated with the region's paleontological heritage—demonstrating a multiplier effect in fostering scientific citizenship.

The positive impact of immersive learning on cognitive outcomes is further corroborated by Makransky and Mayer (2022), who found that VR-based instruction enhances learners' ability to comprehend and retain complex information by providing interactive and engaging experiences.

4 Concluding Remark

The implementation of immersive Virtual Reality (VR) modules at the Universidad Pedagógica y Tecnológica de Colombia's (UPTC) Geology Museum stands as a compelling case of how educational innovation, rooted in local heritage and global pedagogical theory, can transform geoscience and engineering education. The results of this study confirm that immersive learning environments—when grounded in experiential learning principles and developed through interdisciplinary collaboration—can foster deep conceptual understanding, emotional engagement, and knowledge appropriation among diverse learner populations.

One of the most significant outcomes of this project is the successful integration of VR into real-world geological learning contexts, offering a dynamic alternative to traditional lectures and textbook-based instruction. By simulating fossil beds, sediment layers, and mineral formations, the modules provide a vivid, multisensory experience that makes abstract or inaccessible phenomena tangible and relevant. This aligns with Makransky and Mayer's (2022) findings that immersive learning enhances comprehension and retention through presence and interactivity, which are central to multimedia learning theory.

The impact of the VR environments was particularly evident when comparing student performance and feedback before and after experiencing the modules. While conventional teaching methods offer a foundation in theory, VR facilitates faster and more intuitive assimilation of complex geological concepts. University students noted that the VR modules not only reinforced but also expanded their understanding, helping them visualize and manipulate representations of geological processes in ways not possible in the physical classroom. These observations reinforce prior research by Merchant et al. (2014), which found that immersive technologies support superior learning outcomes, especially in STEM disciplines.

Just as importantly, the exploratory engagement observed among schoolchildren demonstrated the platform's ability to democratize access to scientific content. The absence of formal assessments in the experience allowed for unstructured curiosity, leading children to ask questions spontaneously, suggest improvements, and express excitement about what they were learning. Their ability to recognize and discuss prehistoric life forms, environmental features, and even local geographic markers indicates a high level of connection to the content. This level of interaction mirrors what Radianti et al. (2020) describe as "transformational learning," where immersive technologies foster deep emotional and cognitive involvement that can translate into long-term interest and understanding.

Another core strength of the project is its emphasis on local contextualization. By incorporating real fossils from the Boyacá region, including iconic species such as *Sachicasaurus vitae* and *Monquirasaurus boyacensis*, the VR environments became more than just simulations—they became digital extensions of cultural and scientific heritage. This place-based approach increases learner motivation and community relevance, aligning with UNESCO's (2021) calls for the use of digital technologies to preserve and disseminate knowledge of natural and cultural significance.

Incorporating regional content not only promotes heritage recognition but also strengthens learners' sense of belonging and ownership of knowledge. For instance, children were not merely passive users; they became co-creators in the learning experience by suggesting color schemes, sound effects, and navigational features. Their feedback directly contributed to the refinement of the modules, making the project a living example of participatory design. This feedback loop, in turn, reinforces the democratic potential of VR in educational design, as outlined in constructivist learning frameworks.

Institutionally, the project has elevated the role of the UPTC Geology Museum, transforming it into a hybrid educational and outreach platform. The museum's VR modules offer a flexible learning resource that can be adapted to various academic levels—from elementary to higher education—and serve both formal and informal education. This hybrid capacity is particularly important in regions where access to geological field sites may be limited due to financial, geographic, or logistical constraints. VR mitigates these barriers by providing safe, repeatable, and inclusive access to otherwise difficult-to-reach geological phenomena.

Furthermore, the interdisciplinary nature of the project has enhanced academic collaboration within the university. Geology students, museum staff, and systems engineering students worked together across disciplines to design, develop, and test the modules. This process not only enriched the quality of the final product but also modeled the kind of collaborative problem-solving that is increasingly expected in 21st-

century professional environments. The alignment with curricular standards in both geology and systems engineering programs ensured that the modules met educational objectives while encouraging innovation in instructional design.

Looking ahead, the project's success presents multiple opportunities for scalability and replication. The modular nature of the VR environments allows for the addition of new content areas, such as volcanology, hydrology, or structural geology, as well as the integration of multilingual interfaces and accessibility features for users with disabilities. Moreover, partnerships with other educational institutions and museums could extend the reach of the project, making it a national or even international model for immersive science education.

To ensure long-term sustainability, future work will focus on four strategic areas. First, improving user experience by addressing physical discomfort (e.g., dizziness), optimizing spatial orientation, and refining interface ergonomics. Second, integrating formative and summative assessment tools within the VR modules to quantitatively measure learning outcomes, skill development, and user satisfaction. Third, exploring the integration of artificial intelligence and adaptive learning to personalize the learning journey based on user behavior. And fourth, developing partnerships with government and educational agencies to align with public policy objectives on digital education, equity, and scientific literacy.

Finally, this initiative contributes to broader academic discourse on the intersection of technology, culture, and pedagogy. It shows that immersive technologies are not just tools for simulation—they are platforms for inclusive knowledge construction, cultural engagement, and interdisciplinary dialogue. The experience at UPTC reflects a model where local heritage, academic excellence, and technological innovation converge to build an education system that is both globally informed and locally grounded.

In conclusion, the immersive VR project developed at the UPTC Geology Museum affirms the educational value of virtual environments in facilitating deep, engaging, and inclusive learning. It lays the foundation for replicable strategies in higher and engineering education that integrate digital innovation with place-based learning and cultural heritage. More than a technological endeavor, this project is a blueprint for the future of education—one that is interactive, collaborative, and meaningfully connected to the world in which learners live.

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Project based curriculum: multi-case analysis from Brazilian public universities

Lílian Barros Pereira Campos¹, Claudia Akemi Izeki², Walter Aoiama Nagai², Vitor Guilherme Carneiro Figueiredo³, Leonardo Tiago Evangelista², Adriel dos Santos Cunha²

¹ Instituto de Ciências Puras e Aplicadas – Universidade Federal de Itajubá – campus Itabira, Brazil

² Instituto de Ciências Tecnológicas, – Universidade Federal de Itajubá – campus Itabira, Brazil

³ Instituto de Engenharias Integradas – Universidade Federal de Itajubá – campus Itabira, Brazil

Email: liliancampos@unifei.edu.br, claudiaizeki@unifei.edu.br, walternagai@unifei.edu.br, vitorfigueiredo@unifei.edu.br, d2021010746@unifei.edu.br, d2021023510@unifei.edu.br

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Abstract

Driven by changes in workforce demands and educational policies, Brazilian engineering programs are encouraged to adopt active learning strategies to enhance student engagement and align curricula with contemporary challenges. This study investigates the integration of project-based learning (PBL) in engineering education in Minas Gerais. A document analysis of 219 Pedagogical Project Programs (PPPs) revealed that 40 explicitly incorporated active methodologies. Based on Helle et al.'s (2006) classification, 55% of the projects were implemented as components, 24% as exercises, and 21% adopted a project-oriented curriculum. To explore the characteristics of the latter group, a multi-case study was conducted involving two programs: Mechanical Engineering at IFMG Arcos and Electronic Engineering at UNIFEI Itajubá. Data collection involved a combination of document analysis, semi-structured interviews, and a literature review, followed by content analysis. Results highlight key factors for successful implementation, including institutional support, faculty engagement, curriculum flexibility, and resistance management. IFMG's model is based on Integrative Academic Works spanning all semesters, while UNIFEI's curriculum integrates PBL with competency-based education and progressive student autonomy. Despite contextual differences, both cases highlight the importance of aligning curriculum design with labour market needs, fostering interdisciplinary collaboration, and incorporating authentic engineering challenges. The findings contribute to the discourse on curriculum innovation, offering practical insights for institutions seeking to adopt or refine project-based curricula. This research is part of the Engineering Teaching Observatory Project and was supported by FAPEMIG.

Keywords: Active Learning; Engineering Education; Conference Information; Project Approaches.

1 Introduction

The demands of the modern workforce and the evolving characteristics of current generations have driven higher education institutions to seek innovative approaches for modernising education. This transformation is particularly evident in Brazil, where recent curricular guidelines for engineering programs emphasise competency-based education, active learning, and the integration of digital educational technologies. Among these strategies, Project-Based Learning (PBL) has emerged as a transformative tool for fostering meaningful learning and increasing student engagement. By immersing students in real-world projects, PBL not only bridges the gap between theoretical knowledge and practical application but also inspires a new generation of engineers ready to tackle the dynamic challenges of their profession.

Despite its recognised benefits, implementing PBL in engineering education presents significant challenges. When applied beyond individual exercises or isolated components, a comprehensive PBL-oriented approach necessitates fundamental curricular innovation across entire programs. This transformation requires a shift in pedagogical models, faculty development, assessment methods, and institutional support structures. This study examines the adoption of active learning strategies in engineering programs at higher education institutions in Minas Gerais, Brazil.

An analysis of the Pedagogical Project Programs (PPPs) from 219 engineering courses across the state revealed that 40 programs explicitly incorporate active learning methodologies. Based on Helle et al.'s (2006) classification, 55% of these programs integrate projects as components, 24% employ projects as exercises, and 21% embrace projects as the primary orientation for learning. To further explore the implications of PBL-oriented curricula, this study presents a multi-case analysis of two engineering programs that have embraced this model. Through documentary analysis, interviews, and content analysis, the study identifies key factors, including motivators, change agents, institutional contexts, and challenges associated with implementing Problem-Based Learning (PBL).

The study aims to provide valuable insights for other Brazilian engineering programs considering similar curricular innovations by examining these cases. The findings make a significant contribution to the ongoing discourse on curriculum modernisation, engaging institutions in a shared academic conversation and providing practical guidance for those seeking to enhance engineering education through active learning methodologies.

This paper is structured as follows: Section 2 provides a theoretical discussion on Curriculum Innovation and Project-Based Learning, offering a comprehensive overview of the concepts and their relevance to engineering education; Section 3 outlines the methodological procedures used in the study; Section 4 presents the two PBL-oriented curricula cases from UNIFEI and IFMG Arcos; Section 5 discusses the results of the data analysis; Section 6 offers the conclusions drawn from the study; and finally, Section 7 contains the references that support this research.

2 Engineering in Motion: Curriculum Innovation and Project-Based Learning

Changes in labor market demands and new educational guidelines drive the need to reformulate engineering curricula. In Brazil, the National Curriculum Guidelines (DCNs) encourage innovative approaches, such as competency-based education and active methodologies. To train competent engineers, Powell and Weenk (2003) highlight the importance of integrating technical knowledge and interpersonal skills through learning environments that simulate real-world challenges. Furthermore, Keller-Franco and Masetto (2018) point out that traditional approaches, which focus on disciplinary fragmentation and lecture-based teaching, hinder the connection between theory and practice.

Project-Based Learning (PBL) has been widely advocated as a solution to the challenges of engineering education. Helle et al. (2006) emphasise that methodologies such as PBL foster meaningful learning by placing students in authentic problem-solving situations. Vieira Júnior et al. (2017) reinforce this perspective by demonstrating that students exposed to active methodologies, such as PBL, show higher engagement and better knowledge retention throughout their studies.

Project-based learning can be structured in different ways. Helle et al. (2006) identify three levels of PBL implementation:

- Projects as exercises: specific activities within courses.
- Projects as components: courses or modules structured around projects.
- Projects as orientation: an entire curriculum organised based on projects.

The project-based curriculum model offers several advantages, including the development of student autonomy, promotion of interdisciplinarity, and connection to real-world work problems. Keller-Franco and Masetto (2018) emphasise that these elements are crucial for ensuring that students acquire competencies aligned with contemporary societal needs. The project-based curriculum model is also explored by Powell and

Weenk (2003), who describe the experience of the University of Twente with Project-Led Engineering Education (PLEE). This model emphasises collaborative learning and real-world problem-solving as core strategies for engineering education. Weenk and Blij (2011) reinforce the importance of curricular adaptation to ensure the effectiveness of project-based learning, highlighting the need for institutional support and structural changes.

In the Brazilian context, Keller-Franco and Masetto (2018) analyse the implementation of a project-based curriculum at a higher education institution, highlighting its contribution to a more integrated and contextualised education. Similarly, Vieira Júnior (2018) analyses an engineering course based on projects at the Federal Institute of Minas Gerais (IFMG) - Campus Arcos, emphasising that this model can reduce dropout rates and increase student engagement. Vieira Júnior et al. (2017) illustrate how project-based curricula enhance student engagement and practical knowledge application by integrating theory and hands-on problem-solving across the engineering program.

The implementation of PBL in engineering education presents significant challenges. Powell and Weenk (2003) state that transitioning from a traditional curriculum to a project-based one requires profound structural changes, including the development of new assessment formats, the reformulation of teaching materials, and faculty training. Weenk and Blij (2011) reinforce that successful implementation depends on collaboration among faculty, students, and institutional administrators. Vieira Júnior et al. (2017) also note that adapting PBL in Brazilian institutions presents additional challenges, including teacher training and aligning theory and practice within existing curricula.

Helle et al. (2006) also highlight that adopting PBL must be accompanied by careful planning to prevent projects from becoming isolated activities disconnected from the rest of the curriculum. Vieira Júnior (2018) demonstrates that adapting this model to Brazilian reality necessitates structural changes and the involvement of the entire academic community to overcome resistance.

Therefore, analysing engineering programs that have adopted the PBL-oriented approach allows for an understanding of how different institutions have structured their curricula and what challenges and benefits emerge from this adoption. Comparative studies can reveal best practices and effective strategies to overcome barriers, thereby contributing to the improvement of engineering education and the more efficient implementation of this innovative approach.

3 Materials and Methods

This study follows a descriptive research approach (Gonçalves & Meirelles, 2002), the most suitable method for analysing curriculum innovations such as project-oriented curricula. A qualitative research strategy was employed to gain an in-depth understanding of the history and unique characteristics of each case. According to Gonçalves & Meirelles (2002), this approach efficiently describes social phenomena and behaviours within their contexts.

A multiple case study was conducted to achieve the study's objectives. As Yin (2005) highlights, numerous case studies are valuable for testing theories and clarifying complex situations. The research focused on two engineering programs that implemented project-oriented curricula. The first case examined the Mechanical Engineering Program at the Federal Institute of Minas Gerais (IFMG) – Arcos campus. Integrative Academic Works (IAW) were introduced each semester, characterising the program's project-based orientation. The second case analysed the Electronic Engineering Program at the Federal University of Itajubá (UNIFEI), which progressively adopted a Competence- and Project-Based Curriculum, exposing students to design and project techniques from their studies.

Data collection was conducted through three complementary methods: first, interviews were held with two professors—one from each institution—who played key roles in the curriculum innovation process as members of the management committee responsible for overseeing its implementation; second, document analysis was carried out, focusing on the pedagogical project plans (PPP) of both programs to gain a deeper understanding of their specific features; and third, a bibliographic review was performed, drawing on academic papers and book chapters that had previously discussed both cases, thereby offering valuable insights for their analysis.

A content analysis was conducted, integrating theoretical perspectives with the case descriptions, leading to a comprehensive discussion of the findings.

4 Case Studies

This section presents the two case studies analysed in this paper, outlining their history, key innovation agents, challenges, and program structure. Both cases are described based on interviews, documents, and relevant literature available on the subject.

4.1 Case 1: Integrative Academic Work in Mechanical Engineering - Federal Institute of Minas Gerais (IFMG) - Arcos campus

This first case study is from the Federal Institute of Minas Gerais (IFMG), specifically from the Arcos campus, which features a mechanical engineering program designed through Integrative Academic Works (IAW). The professor who described the case was a prominent leader of this movement. The interviewee stated that his motivation for proposing this curricular innovation stemmed from his educational background and prior involvement in pioneering programs, such as the Energy Engineering course at PUC Minas. Upon analysing this program, the interviewee identified an opportunity to design a curriculum that would align with Brazil's national educational guidelines, which are often overlooked in traditional programs. In 2016, he led the creation of a Mechanical Engineering course structured entirely around project-based learning. The foundation of this curriculum is a mandatory subject known as Integrative Academic Work (IAW), present throughout all ten semesters of the program. In each IAW, students engage in practical projects that synthesise the content from their other courses, promoting hands-on learning from the outset of their academic journey.

Within the scope of IAW, each student project is supervised by a lead professor and supported by instructors from related courses. The evaluation process is integrated and collaborative: a committee assesses the student project, with the resulting grade accounting for 30% of each student's final mark in all courses for that term. This method fosters essential skills such as teamwork, organisation, and communication, and encourages sustained interaction between students and faculty in a cooperative learning environment.

The interviewee said that there was significant resistance during the implementation of IAW. Initially, the curriculum proposal was rejected by the institution's academic board, which argued that the structure was unsuitable for an engineering degree. The course was eventually approved after persistent dialogue and justification, though opposition persisted, especially from early faculty members. One experienced professor notably declared that "this was not an engineering course" and refused to participate in the first TAI week. Over time, after witnessing the effectiveness of the method and the depth of student learning, he became one of its strongest proponents.

Other faculty members hesitated to assign part of their course grades to a collective project. To address this, the leadership organised technical visits and invited experts to lecture, gradually winning over sceptical professors.

According to the interviewee report, despite growing acceptance, maintaining the IAW strategy requires ongoing effort, which demands continuous collaboration and extra dedication from all involved. The IAW projects are more than simple science fair displays—they are genuine engineering challenges that require scientific justification, material selection, cost analysis, and functional proof. Students must defend their work before a panel, explaining the reasoning behind their design choices. This process develops their confidence, communication skills, and collaboration abilities. The interviewee mentioned that one impactful example involved a simulation project for a Baja car, which attracted the attention of a local entrepreneur and opened the door for potential partnerships.

As reported by the interviewee, students often express frustration over the heavy workload during the semester. Nevertheless, they consistently acknowledge the value of the experience at its conclusion. Faculty also observe that IAW motivates students to seek advanced knowledge early, breaking the monotony of theory-heavy instruction.

Regarding the main benefits of IAW, the interviewee mentioned that the program includes additional short courses on topics such as 3D modelling and optimisation, thereby enriching the students' learning experience. One of the initiative's results is earning course awards at academic conferences and achieving international recognition. The initiative promotes integration among students, faculty, administrative staff, and the wider community. It requires careful planning, teamwork, and adherence to strict deadlines. Administrative staff even evaluate student presentations, reinforcing the collaborative spirit of the program. Due to its success, the IAW model has been adapted to the technical high school curriculum, where project-based evaluation now plays a central role in the curriculum. This success has also inspired other campuses to experiment with active learning methods on a smaller scale, as sweeping reforms often face resistance. Faculty are encouraged to try new approaches without fear of failure, always striving to enhance educational quality.

4.2 Case 2: Competence and Project-based curriculum in Electronic Engineering - Federal University of Itajubá (UNIFEI) - Itajubá campus

The second case study presents the experience of modernising the Electronic Engineering program at UNIFEI (Federal University of Itajubá), Brazil. This program began in 2010 and gained momentum in 2018, thanks to support from the Capes-Fulbright Undergraduate Modernisation Program. The primary objective was to implement Project-Based Learning (PBL) to integrate practical activities throughout students' academic journey, preparing them for professional challenges with hands-on experience in project development.

As the interviewee reported, UNIFEI has a long-standing tradition of emphasising practical education. The Electronic Engineering program, established in 2010, incorporated Problem-Based Learning (PBL) from the outset. The curriculum was designed to immerse students in long-term, complex projects, such as developing electronic boards and devices, as well as simulating real-world engineering challenges. This approach exposed the complete project cycle, from layout to fabrication and testing.

As reported by the interviewee, the program underwent several restructurings over the years, notably in 2015 and 2018, to enhance professional training and integrate practical knowledge with theoretical foundations. The 2018 reforms, supported by Capes-Fulbright, introduced a competency-based curriculum rather than a content-driven one (Almeida et al., 2021) — these changes aligned with new engineering curricular guidelines, emphasising practical skills in telecommunications and instrumentation. Greater flexibility in elective courses was also introduced.

The curriculum reform aimed to align competencies and content with market needs and regulatory guidelines. The structuring teaching nucleus (NDE) adopted three key guidelines or methodologies to support the development of the program's pedagogical project. The first was competency-based education, intended to

create a coherent structure that connects the graduate profile, required skills, and curricular content, drawing on the CDIO methodology and the new DCNs. The second was Bloom's Revised Taxonomy, which defined the expected proficiency levels for graduates in each competency and skill, considering both knowledge acquisition and cognitive development. The third guideline focused on gradually increasing student responsibility. To apply this principle, course structures were designed to promote the transition from passive to active learning, empowering students to take ownership of their educational journey. The PETRA model informed the overall curricular design, incorporating the PBL methodology (Almeida et al., 2021).

According to the interviewee report, technological trends and market demands were key considerations in adapting the curriculum. For instance, the growing importance of Field-Programmable Gate Arrays (FPGAs) was acknowledged, although they were not yet widely used. The course structure shifted to focus on shaping graduates capable of designing technological solutions, rather than merely following traditional engineering approaches. This evolution was not linear; continuous adjustments ensured the curriculum remained relevant to academic and industry standards.

Developing the curriculum involved defining necessary competencies and skills. The initial research phase lasted about eight months, during which faculty collaborated to align content with competency requirements. Drafting the first version of the curriculum took a week, followed by three to four weeks of refinement and revision.

As mentioned by the interviewee, the graduate profile was categorised into three potential roles: developer, designer, and manager, allowing students to prioritise one. Competencies were divided into technical (hardware development, programming) and non-technical (communication, teamwork) categories — the revised Bloom's Taxonomy structured learning objectives ensured efficiency by reducing unnecessary overlaps between courses. The content was integrated, eliminating traditional subject divisions to optimise learning and better prepare students for the job market.

As reported by the interviewee, the 2021 curriculum was structured to reinforce student knowledge through intentional repetition. Encountering the subject multiple times ensured mastery rather than reliance on memorisation. Classroom hours were reduced in favor of increased practical activities and lab sessions, fostering applied learning. This change also provided students with more time for internships and projects, thereby enhancing their flexibility and engagement with real-world experiences. The curriculum emphasised competency development, ensuring each course contributed directly to professional growth. A humanistic education component was also incorporated, integrating courses on communication, economics, and ethics to cultivate socially responsible engineers.

Competency validation was conducted through discussions with alumni and faculty researchers, ensuring alignment with industry trends. A strategic reorganisation of subjects reduced the total curriculum workload from 3,800 to 3,600 hours. Introductory courses were integrated into technical courses to create greater synergy. For example, differential equations and calculus were incorporated into control and electromagnetism courses, optimising class time without compromising essential content.

The program's structure followed a progressive learning path, beginning with general and theoretical courses and advancing toward practical applications and projects. Specific PBL modules facilitated the systematic development of skills. The evolution of the curriculum involved continuous revisions and faculty discussions aimed at maintaining relevance. Some courses remained mandatory due to regulatory requirements or their technical significance. In contrast, others were converted into electives or eliminated if they did not contribute to the desired competencies, resulting in a more flexible and coherent curriculum that supports the development of skills aligned with the profession's needs and expectations for student achievement.

According to the interviewee report, the project-based courses in the Electronic Engineering program offer a structured learning experience that focuses on real-world applications. To ensure that engineering students are exposed to design techniques from day one, four first-year courses were adapted to integrate peer instruction into their teaching methodology. The ELTA00 course introduces circuits and analogue electronics, while ELTA01 builds on this foundation by advancing to diode and transistor circuits. ELTE01 covers scientific methodology and learning theory, fostering metacognitive skills and peer learning, and ELTE02 focuses on human-machine interaction, emphasising usability and empathy in design.

In the third semester, the PBLE00 course introduces the first open-ended project, in which students design a robust physical protection system for an electronic device while ensuring proper heat dissipation.

PBLE01 (fourth semester) and PBLE02 (fifth semester) are interconnected, with PBLE01 focusing on hardware development and PBLE02 focusing on software implementation for the same product. Industry-standard tools are used and updated annually, allowing students to gain relevant hands-on experience. Teams of three start with predefined requirements to ensure project continuity between courses. PBLE02 course is dedicated explicitly to firmware development, with students first creating a self-testing tool for production lines and later implementing a complete human-computer interface.

In the sixth semester, the PBLE03 course involves designing a current-loop-based measurement system using only analog components. Students address precision, stability, and sensor reproducibility while working on circuit design, instrumentation, and analog electronics.

The PBLE04 course introduces FPGA-based development in the seventh semester through a Software-Defined Radio (SDR) project. This course integrates signal modulation, telecommunications theory, and FPGA technologies, thereby strengthening competencies in telecommunications and firmware development.

Finally, in the eighth semester, the PBLE05 course focuses on project management and entrepreneurship. Students explore launching and managing a hardware-based company, understanding the relationship between product development, administration, production, and marketing. Project management methodologies are also covered, preparing students for real-world business challenges.

According to the interviewee report, a crucial aspect of the curriculum was its emphasis on lifelong learning. A dedicated course taught students effective study methods, which are essential for adapting to the new teaching model. The redesigned curriculum strikes a balance between theoretical knowledge and practical experience, aligning with job market demands and preparing students for future challenges.

By shifting from traditional lecture-based teaching to a competency-focused, hands-on approach, UNIFEI's Electronic Engineering program ensures graduates are well-equipped to navigate the evolving engineering landscape. Integrating practical activities, market-driven competencies, and humanistic education cultivates well-rounded professionals who are capable of innovating and leading in their field.

5 Discussion

The two case studies presented — Integrative Academic Work in Mechanical Engineering at the Federal Institute of Minas Gerais (IFMG) and the Competence and Project-Based Curriculum in Electronic Engineering at the Federal University of Itajubá (UNIFEI) — illustrate different approaches to implementing Project-Based Learning (PBL) within engineering education in Brazil. Both cases align with the theoretical framework that emphasises competency-based education, active methodologies, and curricular integration to meet labour market demands and national educational guidelines.

The IFMG-Arcos approach relies on a mandatory subject (IAW) spanning all ten semesters, integrating learning through interdisciplinary projects. This model ensures that PBL remains a consistent and central component of the student's educational experience. In contrast, UNIFEI adopts a more modular approach, embedding PBL principles within specific courses that progressively develop competencies throughout the program. While IFMG focuses on a single integrative framework, UNIFEI structures PBL through competency-based development, aligning each course with a defined skill set.

Both cases encountered faculty resistance during implementation. At IFMG, scepticism was initially strong, with some faculty members questioning whether the approach was suitable for an engineering program. Over time, technical visits, expert lectures, and demonstrated student success contributed to increasing faculty acceptance. At UNIFEI, the faculty played a crucial role in shaping the curriculum, defining competencies, and structuring content around real-world engineering challenges. The success of both models underscores the importance of faculty engagement and continuous professional development in facilitating curriculum reforms.

Both institutions emphasise the importance of real-world application in engineering education. IFMG's IAW model enables students to tackle engineering challenges, such as designing Baja car simulations, which attract the attention of industry professionals. Similarly, UNIFEI ensures market alignment by integrating emerging technological trends, such as FPGA-based development and software-defined radio projects. By reducing classroom hours and increasing hands-on activities, UNIFEI's curriculum better prepares students for the demands of the industry.

Implementing PBL in both institutions required overcoming significant resistance from faculty and institutional boards. The IFMG case highlights the importance of maintaining persistent dialogue and gradually involving faculty, while the UNIFEI case underscores the role of structured discussions and research-driven curriculum development. A common challenge in both cases is the heavy workload associated with PBL. IFMG students initially express frustration but later recognise the value of hands-on learning. Similarly, UNIFEI students experience a gradual shift toward greater autonomy, supported by structured competency development.

Maintaining PBL effectiveness requires continuous effort. At IFMG, ongoing collaboration among faculty, students, and administrative staff ensures that IAW remains a cornerstone of the program. At UNIFEI, iterative curriculum adjustments based on industry feedback help sustain the relevance of the competency-based approach. Both cases demonstrate that successful PBL implementation is not a one-time reform but a continuous process of adaptation and refinement.

6 Conclusion

These case studies reinforce the broader theoretical perspective that active methodologies enhance student engagement, knowledge retention, and employability when well-integrated into the curriculum. The IFMG model demonstrates the potential for interdisciplinary, institution-wide project integration, while UNIFEI's approach showcases how structured competency-based education can drive student development.

The success of these models suggests that future engineering programs should consider ensuring faculty buy-in through professional development and exposure to successful PBL implementations, aligning with industry trends to ensure that graduates possess relevant skills. This should involve integrating assessment strategies that reflect real-world problem-solving and collaboration and providing institutional support to sustain curriculum reforms over time. By addressing these factors, engineering programs can effectively transition toward innovative, competency-based education that aligns with contemporary societal and market needs.

From the perspective of the Innovations in Engineering Teaching Observatory Research Project, the analysis of these two cases brings essential reflections on how curricular innovation occurs in this context. However, it is necessary to note that this research has limitations, and the generalisation of the results presented here is also restricted to the context from which they originated. Given the complexity of curricular innovations, faculty members and administrators from different institutions must consider their specific characteristics and determine which approaches best fit their respective contexts.

Furthermore, it is essential to highlight that this research is still ongoing and will incorporate data collection from faculty members at institutions involved in the project, as a strategy to investigate how these practices influence the classroom, an essential locus of analysis for understanding the phenomenon in question.

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Pedagogical Relationship and Teaching Strategies in Higher Education: The Students' Perspective

Francisca Miranda¹, Inês Monteiro¹, Diana Soares¹

¹ Universidade Católica Portuguesa, Faculty of Education and Psychology, Research Centre for Human Development, Porto, Portugal

Email: fmiranda@ucp.pt, imfsantos@ucp.pt, dsoares@ucp.pt

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Abstract

The pedagogical relationship and the relational climate in the classroom are dimensions identified as crucial for the academic performance and well-being of university students. Therefore, understanding the dynamics of this relationship and identifying the teaching methods most valued by students is essential to promoting more effective teaching. The present study aimed to answer the following research questions, based on university students' perceptions: How do students characterize their pedagogical relationship with teachers?; How does teacher interaction and involvement influence the student learning experience?; Which classroom models and teaching strategies are most valued by students?; What types of materials and resources provided by teachers are most valued by students? The study involved 151 university students from a Portuguese higher education institution, mostly female (51.7%) and aged between 18 and 54 years old ($M = 20.15$; $SD = 3.26$). The students were attending a bachelor's (94.7%) or master's degree (5.3%) in different areas: Management (66.2%), Psychology (12.6%), double program in Law and Management (11.3%), Economics (5.3%), Accounting and Finance (2.0%), Master of Science (0.7%), Microbiology (0.7%), and Sound and Image (0.7%). They were asked to complete an online questionnaire that included, in addition to sociodemographic characterization questions, six open-ended questions. Sociodemographic data were analyzed using IBM SPSS, and NVIVO facilitated the content analysis of the open-ended questions. The results point to a positive pedagogical relationship, with teachers' availability being particularly notable. Data shows that teacher interaction and involvement are considered essential to the learning experience, as supportive and engaged teachers facilitate content understanding and increase student motivation. Students seem to value class models that combine lectures with debates, case studies, and practical projects, and they appreciate practical materials such as solved exercises and slides presentation. The results will be discussed in light of the practical implications for improving the quality of learning in higher education.

Keywords: Higher Education; Pedagogical Relationship; Teaching Strategies; Student Perceptions.

1 Introduction

1.1 Pedagogical relationship and its influence on students' learning experience

The pedagogical relationship, or student-teacher relationship, involves establishing and maintaining a climate and culture of trust, care, and autonomy within the classroom, forming an integral component of the educational process in higher education (Hollweck et al., 2019; Katsogridakis & Leather, 2025). As such, it is crucial to consider this multidimensional construct in the learning process to foster an environment of care, interaction, and trust, which are essential in the classroom setting (Hagenauer & Volet, 2014; Okoye, 2023; Tormey, 2021).

Based on the literature, Hagenauer and Volet (2014) identify two fundamental dimensions of the pedagogical relationship: affective and supportive. The affective dimension refers to the bond that is established between students and teachers, serving as the foundation for a trust-based relationship. It includes elements such as honesty, trust, and respect. The supportive dimension refers to the assistance provided by teachers to promote and facilitate students' academic success.

The pedagogical relationship involves various social roles that influence the personal and social characteristics of both students and teachers within educational contexts (Okoye, 2023). According to the literature (e.g.,

Aspelin & Jonsson, 2019; Hagenauer & Volet, 2014; Katsogridakis & Leather, 2025; Parnes et al, 2020; Tormey, 2021), positive student-teacher relationships significantly impact the learning experience and development of higher education students. These relationships contribute to enhanced self-perception of effective and meaningful learning; improved academic performance; increased commitment, effort, persistence, motivation, and engagement in the learning process; more positive and adjusted behaviour; perception of a more welcoming learning environment; a greater sense of belonging; and the fostering of intellectual development, including critical thinking skills (Aspelin & Jonsson, 2019; Hagenauer & Volet, 2014; Katsogridakis & Leather, 2025; Parnes et al, 2020). Consequently, strong pedagogical relationships reduce the likelihood of students failing and dropping out of the university (Hagenauer & Volet, 2014; Parnes et al., 2020; Tormey, 2021). This aligns with Okoye's (2023) findings, which show that university students value teachers who create an environment where students feel free to share their opinions, who care about their academic development, and who establish relationships based on mutual respect.

Despite the evidence highlighting the importance of the pedagogical relationship for the learning experience, across all study cycles, but here particularly in higher education, some teachers prioritize establishing this relationship more than others (Hagenauer & Volet, 2014). Some teachers face resistance or difficulty in forming a relationship with their students due to large class sizes, fear of contempt from students, and due to their individual characteristics (Okoye, 2023). Additionally, factors such as the characteristics of the university, the program, the educational philosophies of the teacher, and the characteristics and background (cultural, ethnic, and socioeconomic) of the students and teachers involved influence the establishment and quality of pedagogical relationships (Katsogridakis & Leather, 2025; Parnes et al., 2020).

1.2 Teaching strategies in higher education

To enhance the teaching and learning process, it is essential to assess and understand the preferred teaching strategies of higher education students (Bazán-Perkins & Santibañez-Salgado, 2025). By adapting their teaching practices based on these preferences, teachers can not only improve the effectiveness of learning, but also positively influence students' interest, engagement, and academic performance (Bazán-Perkins & Santibañez-Salgado, 2025; Vercellotti, 2018).

The literature identifies two primary approaches to teaching (e.g., Bhardwaj et al., 2025): teacher-centered approach and student-centered approach. In the first one, a more traditional educational paradigm, the teacher occupies a central role in the dissemination of knowledge and serves as the primary authority in the teaching and learning process. This approach involves the teacher structuring the curriculum, preparing and delivering lectures, and evaluating students' performance, typically through final exams (Bhardwaj et al., 2025; Murphy et al., 2021; Woods & Copur-Gencturk, 2024). Students are placed in the passive role of listeners, without any intentional stimulation of fundamental skills for their academic, professional, and personal development, such as critical thinking and problem-solving skills, and creativity (Bhardwaj et al., 2025). In this approach, teachers focus on lectures, with texts and supplementary materials to reinforce the content covered in class (Bhardwaj et al., 2025). However, this approach has been criticized, particularly for its focus on memorizing content (although very effective at conveying foundational knowledge) rather than understanding it, and for not fostering the development of skills needed in the real world (Ahmod & Zhang, 2021; Kálmán et al., 2020). Consequently, this traditional approach has been complemented by active, student-centered methodologies. These methodologies emphasize active learning, incorporating various strategies that prioritize student autonomy and engagement (Freeman et al., 2014). In these methodologies, the focus is on creating meaningful learning experiences aimed at fostering knowledge construction by the student, as well as promoting effective understanding and the development of competencies (Bhardwaj et al., 2025; Freeman et al., 2014). In a student-

centered approach, teachers adapt their teaching strategies to ensure that each student can succeed, empowering them to play an active role in their learning process (Bhardwaj et al., 2025).

Although higher education institutions (HEIs) are (starting to) implementing a student-centered approach and active learning methodologies (Bhardwaj et al., 2025), lectures are still the most common teaching strategy (Ahmod & Zhang, 2021; Álvarez-Álvarez & Falcon, 2023; Bazán-Perkins & Santibañez-Salgado, 2025). Nevertheless, there are other strategies that are often used in higher education, such as seminar and tutorial, independent study, practical learning, fieldwork, enquiry-based learning (EBL), project, e-learning, and learning by research (Ahmod & Zhang, 2021). On the other hand, the teaching strategies least experienced by students in higher education are those related to active learning, as highlighted in the study by Gonsar et al. (2021).

Although there is evidence on the most used teaching strategies in higher education, there are few studies that specifically explore student preferences regarding these methodologies (Álvarez-Álvarez & Falcon, 2023). Nevertheless, Álvarez-Álvarez and Falcon (2023) showed that higher education students prefer teaching practices that emphasize clarity and interaction/relationship, i.e. they value teachers who present ideas and activities in a clear, organized, and well-planned way, as well as methodologies that promote interaction between teachers and students and the students themselves, allowing sharing ideas, concerns, and support during the learning process. This is supported by Gonsar et al. (2021), who showed that students would prefer to have more active learning approaches than they are experiencing, such as peer-assisted learning. Bazán-Perkins and Santibañez-Salgado (2025) also recommend that students work collaboratively, sharing and discussing learning materials with each other. On the other hand, Deslauriers et al. (2019) showed that despite active learning leading to better performance, students tend to perceive they are learning less than in passive classes, making them more likely to prefer lectures.

1.3 Purpose of the study

With this theoretical framework in mind, the following research questions were defined:

Based on university students' perceptions:

- 1) How do students characterize their pedagogical relationship with teachers?
- 2) How does teacher interaction and involvement influence the student learning experience?
- 3) Which classroom models and teaching strategies are most valued by students?
- 4) What types of materials and resources provided by teachers are most valued by students?

2 Methodological procedures

2.1 Participants

The present study was conducted at a Portuguese higher education institution, a multi-campus university located in four cities in Portugal. It offers bachelor's, master's, and PhD programs in different areas, such as: Biotechnology, Dental Medicine, Law, Management, Nursing, Psychology, Social Work, Sound and Image, among others.

The study involved 151 university students, mostly female (51.7%) and aged between 18 and 54 years old ($M = 20.15$; $SD = 3.26$). They were attending a bachelor's (94.7%) or master's degree (5.3%) in different areas: Management (66.2%), Psychology (12.6%), double program in Law and Management (11.3%), Economics (5.3%), Accounting and Finance (2.0%), Master of Science (0.7%), Microbiology (0.7%), and Sound and Image (0.7%).

2.2 Materials

For data collection, a questionnaire was developed and administered to the participants. Along with sociodemographic and academic data, it included six open-ended questions, as follows: (i) The pedagogical relationship (teacher-student interactions) and the relational climate in the classroom are important dimensions in the academic performance and well-being of university students. How do you characterize the pedagogical relationship in your experience as a higher education student? (ii) What are the indicators of a good relationship for you? (iii) How does the interaction and involvement of teachers influence your learning experience? (iv) Could you share a specific situation from your university experience in which you felt that the teaching relationship had a positive impact on your learning? (v) Which model of teaching/activities do you value most? (vi) What kind of materials and resources provided by teachers do you value most?

2.3 Procedures

The questionnaire was sent by e-mail to all students attending one of the campuses of the Portuguese higher education institution. Therefore, students were asked to complete an online questionnaire via Google Forms between May and July 2024. To ensure ethical and deontological issues, informed consent was obtained from all the participants. They were informed of the objectives of the study, the possibility of withdrawing at any time without any prejudice, and the anonymity and confidentiality of the data was safeguarded, according to the Declaration of Helsinki. Participation in the study was voluntary.

This study received ethical approval from the Ethics Committee in Technology, Social Sciences and Humanities (approval no. CETCH2024-83), of *Universidade Católica Portuguesa*.

Sociodemographic and academic data were analyzed using IBM SPSS software (descriptive statistics) and NVIVO facilitated the content analysis of the six open-ended questions. This qualitative analysis was organized into three stages: pre-analysis, material exploration, and data processing and interpretation (Bazeley & Jackson, 2013). At first, a floating reading of the data was carried out and then the data was categorized into themes and categories, following a semi-inductive analysis (Bazeley & Jackson, 2013; Resende, 2016).

3 Results

The presentation of the results will be supported by examples of the participants' answers, safeguarding anonymity and confidentiality.

3.1 How do students characterize their pedagogical relationship with teachers?

Most students report having a positive pedagogical relationship with their teachers, describing it as positive/good (67 references), close (25 references), very good (19 references), cordial (6 references), motivating (3 references), welcoming (3 references), calm (2 references), important (2 references), and rewarding (1 reference). Examples from the students' narratives include: "I consider it to be good; teachers were always willing to answer any question, and quickly" (male Management student); "In my experience, the pedagogical relationship in higher education is characterized by accessible and interactive teachers, the use of varied methods, constructive feedback, mutual respect, and encouragement of student autonomy" (male Management student).

Moreover, one notable aspect that emerged from the data was the availability of teachers (45 references), as reported, for example, by a Psychology student: "In a second-year course, I had to give a 45-minute group presentation, and the teacher's involvement was crucial. She consistently made herself available to help us, regularly checked on our progress, and in every meeting, paid close attention to how each student was feeling."

On the other hand, some students perceive their pedagogical relationship with teachers less positively, describing it as negative or distant (16 references), or even “indifferent” (male Economics student), “unsatisfactory” (female double degree student in Law and Management) or “stressful” (male Management student). Examples of negatively perceived pedagogical relationship include: “there is no relationship with most of the teachers, nor do they seem approachable in most cases” (female Management student); “I feel that there is typically some distance, although some teachers try to counteract this” (female double degree student in Law and Management).

Additionally, a few students characterize the pedagogical relationship as reasonable (11 references). One student pointed out that this relationship “varies depending on the teachers and the type of classes. In practical classes it's easier to have a better pedagogical relationship, as the teacher only interacts with one group of students” (female Management student), while another highlighted the existence of “an unbalanced power relationship” (female double degree student in Law and Management).

Additionally, students identified what they considered to be the indicators of a quality pedagogical relationship. These indicators include aspects such as availability and attentiveness (82 references), effective communication (67 references), respect and empathy (53 references), closeness and trust (32 references), and a professional and inspiring attitude from the teacher (31 references).

3.2 How does teacher interaction and involvement influence the student learning experience?

According to the university students' perception, the interaction and involvement of teachers influences their learning experience, impacting their motivation and involvement (90 references), and the learning process (64 references) and environment (57 references).

Students believe that increased interaction and involvement from teachers positively impacts their “motivation to perform in the subject” (female Sound and Image student), their desire “to learn” (male Management student), and their willingness “to attend classes and study the subject more deeply” (male Management student), thereby “increasing interest in the subjects” (female Psychology student). This enhanced engagement leads to greater “motivation to attend classes” (female Management student) and, consequently, a “lower risk of dropping out” (female Psychology student). As such, “the interaction and involvement of teachers influences everything related to learning, such as motivation, understanding of the content, interest in it, the classroom environment, among other equally important things” (female Psychology student). Other examples of participants' responses include: “The interaction and involvement of teachers has a very significant impact on my development as a student. I tend to enjoy the subjects more and feel more motivated when there is a good relationship with the teachers” (female Economics student); “In my experience as a university student, the pedagogical relationship is crucial to academic success. Approachable and caring teachers create a positive learning environment, where doubts are answered with patience and encouragement. Constant interaction and constructive feedback contribute to a healthy relational climate, which in turn fosters student motivation” (female Management student).

In addition to motivation, teacher interaction and involvement also appears to enhance the quality of students' learning. As one student noted, “If a teacher enjoys what they do, is consistent, relates examples from the real context to the content they are teaching, and shows research and up-to-date knowledge, learning will be more meaningful and closer to what the real experience will be” (female Psychology student). Another student observed “When there is greater support, there is greater evolution and quality in the work produced. When there isn't, there are negative impacts on academic satisfaction and mental health” (female Psychology student). Additionally, a student shared an experience from a math class: “The teacher used practical examples

and focused on relating the content to real-world situations. He was also always available to answer questions and offered to answer questions outside of teaching hours. This practical approach and constant support had a positive impact on my understanding of the subject and my academic performance" (female Management student).

Moreover, according to the participants, more interactive and involved teachers establish a safe environment for questioning and reflection: "The interactions with the teachers were close and easy to communicate with. This improved my perception of confidence and security in acquiring content as well as putting me at ease to question and reflect on things" (female Psychology student); "Knowing that I can speak without fear of being judged, that the person is really listening to me, and that what they are going to tell me is for my own good" (female double degree student in Law and Management). Additionally, teachers who interact frequently with students "promote a more collaborative and inclusive environment" (female Management student).

Only one male Management student did not consider that the teachers' interaction and involvement influence his learning experience.

3.3 Which classroom models and teaching strategies are most valued by students?

The participants mainly value classes with active methodologies (182 references), such as debates (75 references - "I think debates really prepare us for the job market", male Management student), case studies (53 references), projects (50 references), and teamwork/collaborative work (4 references). With less emphasis, students also value lectures (29 references), classes with practical application (11 references), and classes that combine these two approaches, active lectures (9 references). According to a Psychology student, "if teachers know how to combine the lecture model with other models such as project/work presentations, debates, innovative strategies such as podcasts, among others, students will have more interest and initiative".

Two students also highlighted the importance of "interactive classes" without providing much detail, while another student mentioned the value of "classes with guest speakers."

3.4 What types of materials and resources provided by teachers are most valued by students?

Students value different types of materials and resources provided by teachers: class support material (102 references), knowledge application and assessment resources (56 references), digital and multimedia resources (21 references), and practical and applied resources (20 references). Class support materials encompass PowerPoint presentations (49 references), supplementary texts (25 references), scientific articles (14 references), and summaries of lesson content (13 references). Examples of resources for applying knowledge include exams or tests from previous years (27 references) and exercise solutions (26 references). Digital and multimedia resources primarily consist of videos (13 references), but also include lesson recordings (1 reference), documentaries (1 reference), and podcasts (1 reference). Some digital resources were not specified by the students. Finally, practical resources involve the analysis of real-world cases (11 references) and newspaper reports (3 references), among others.

4 Discussion

The results of the present study indicate that, for the most part, students feel they have a positive relationship with their teachers. Although they didn't elaborate much on this relationship, they did identify the indicators which, for them, constitute a good relationship and which can characterize this positive pedagogical relationship. The indicators identified are in line with two dimensions of the pedagogical relationship: affective (honesty, trust, and respect) and supportive (availability, caring, encouragement) (Hagenauer & Volet, 2014).

These findings are also consistent with those of Ahmod and Zang (2021), who identify that both teachers and students consider respect, a friendly environment, understanding, availability, and concern as essential for effective instruction. The dimensions of care, respect, and concern are also found in the studies of Katsogridakis and Leather (2025) and Okoye (2023). However, some students describe this relationship as distant, suggesting that some teachers value establishing a close relationship with their students more than others (Hagenauer & Volet, 2014). Therefore, some students consider this relationship to be positive and close, while others perceive it to be more distant. As all students are from the same university, possible factors that could explain this difference are the class size, the program, and the characteristics and backgrounds of the students and teachers (Katsogridakis & Leather; Okoye, 2023; Parnes et al., 2020).

According to students' perceptions, teacher interaction and involvement influences their learning experience, as highlighted in the literature (Hagenauer & Volet, 2014; Katsogridakis & Leather, 2025; Okoye, 2023; Parnes et al., 2020; Tormey, 2021), translating into a more positive learning environment and effective learning. This is in line with Okoye (2023) who points that a strong pedagogical relationship, characterized by teacher involvement and interaction, leads to more motivation, more engagement, and better student academic performance. This is also consistent with Hagenauer and Volet (2014) and Parnes et al. (2020), who emphasize that students become more committed, engaged, and harder-working in their learning process when there is greater interaction and involvement from teachers, leading to more effective learning, greater class attendance, and a lower risk of drop-out. Besides, greater teacher interaction and involvement foster a perception of safety, allowing students to feel comfortable sharing their opinions, as also identified by Okoye (2023). Consequently, teachers who are more committed and engaged in the learning process contribute to a better and richer learning experience.

Regarding teaching strategies, lectures, which are typically the most used (Ahmod & Zhang, 2021; Álvarez-Álvarez & Falcon, 2025; Gonsar et al., 2021), are not the strategy most valued by the students in the present study. They prefer active methodologies, emphasizing student-centered teaching and learning (Bhardwaj et al., 2025). Students value moments of interaction, which enable an exchange of ideas and experiences, as is in debates, in line with the findings of Álvarez-Álvarez and Falcon (2025) and Gonsar et al. (2021). The moments of discussion in class, incorporated into the strategies most valued by the students (debates, case studies, projects, and teamwork/collaborative work), are particularly useful for promoting critical thinking skills and the development of knowledge (Ahmod & Zang, 2021). Data also suggests a preference for a combination of the teacher-centered approach and the student-centered one, through active lectures. This strategy emphasizes student involvement and participation during lectures, involving activities and tools to promote high order thinking skills and deep learning (Gregory, 2013).

Although students value exercises and resources that allow them to apply knowledge, the most highly valued are class support material and supplementary texts, typically more associated with lectures (Bhardwaj et al., 2025). Nevertheless, students may prefer more active teaching strategies, but they may study better through more theoretical resources and materials, as they allow for more structure. This information on the strategies, resources, and materials most valued by students can help teachers to plan and structure their lessons. But a question arises: despite being the most valued teaching strategies, are they the ones that lead to the best achievements? This idea was highlighted by Deslauriers et al. (2019) who showed that higher education students may value a particular method but perform better with another one. The most valued strategies may not be the most effective ones for students' development and learning.

5 Conclusion

The present study aimed to explore how university students characterize their pedagogical relationship with teachers, how the teacher interaction and involvement influence their learning experience, and the classroom models, teaching strategies, and types of materials and resources most valued by the students.

Most of the students characterize their relationship with teachers as positive, with teachers' availability being highlighted. However, some students characterize this relationship as distant. This relationship and teacher interaction and involvement significantly influences students' learning experience, particularly their motivation and engagement. Teaching strategies also impacts the student learning experience and the participants value more active methodologies. As for the resources and materials provided by the teachers, class support material are the most valued ones. This study also identifies the indicators that constitute, according to students' perceptions, a good pedagogical relationship. Understanding how the students characterize their relationship with teachers, as well as the factors that can contribute to the development of this relationship, can give insights to teachers to promote meaningful relationships and, consequently, optimizing the learning process. Besides, identifying the teaching strategies and the resources and materials most valued by students is also highly relevant, so that teachers can enrich their practices, considering students' interests and, therefore, fostering greater academic development.

On the other hand, the study has limitations such as the possible influence of social desirability bias, with participants responding as they see most appropriate or socially desirable, particularly as we are addressing issues involving teachers. Moreover, many studies focus on the student-teacher interaction, but a few analyze or describe the quality of that relationship (Hagenauer & Volet, 2014). The present study aimed to explore this relationship and the influence of teacher interaction and involvement, but focusing on students' perceptions. In future studies, this could be complemented by a quality evaluation of this relationship through validated instruments. The investigation also showed the teaching strategies, resources, and materials most valued by higher education students, but it would be also interesting and relevant to identify those that have the greatest impact on their learning. Are the most valued ones also the most effective? Addressing this question in future work could provide valuable insights for evidence-based pedagogical practices.

Based on this study, it is important to note that, despite the challenges teachers may face, establishing a quality relationship with students is crucial. Teachers could develop and maintain a climate and culture of trust, availability, and care (Hollweck et al., 2019), and so teacher training should emphasize the development of relational skills. Although teachers recognize some student resistance to active learning, they value this methodology and express a desire to experience it more frequently (Gonsar et al., 2021). Therefore, teachers may consider incorporating active learning strategies into their practices to enhance the educational experience. In terms of implications for higher education, this study suggests that curricula could be structured to promote student-centered learning environments by integrating active methodologies that foster interaction, collaboration, and autonomy.

To conclude, student-teacher relationship, teacher interaction and involvement, and teaching strategies are crucial to developing a positive and effective learning environment. By focusing on these dimensions, HEIs and academic staff can significantly enhance student learning.

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Bridging Innovation and Sustainability in Engineering Education: work in progress

Marien Rocio Barrera Gómez¹, Liliana Fernández-Samacá¹.

¹ Universidad Pedagógica y Tecnológica de Colombia, Sogamoso, Boyacá

Email: marien.barrera@uptc.edu.co, liliana.fernandez@uptc.edu.co

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Abstract

Institutional models for innovation in engineering education play a critical role in shaping students' mindsets to address complex challenges in their professional careers. Thus, this research focuses on a framework development inspired by student-centered approaches to improve the mindset of bringing theoretical knowledge into practical, sustainable, and innovative solutions in engineering education. The need for this framework is associated with graduates struggling to meet the demands of a rapidly evolving labor market. It reflects a broader global challenge of preparing students to address complex 21st-century issues like climate change and social inequality. A comprehensive literature review revealed that while student-centered approaches have proven effective in fostering creativity and innovation, empirical evidence does not connect these methods directly to sustainability outcomes. Furthermore, this review identified key gaps in aligning engineering education with the competencies required for sustainable development. The research will employ a mixed-methods and practice-oriented approach, incorporating qualitative and quantitative data collection techniques to capture the multifaceted nature of the learning process involving experimental interventions with engineering students. This process involves four stages: literature review, approach design, implementation and evaluation, and framework refining. This work is in progress, specifically in the first stage. The preliminary findings present the first-stage results. Preliminary findings suggest a complementary relationship between sustainability and innovation: sustainability sets the overarching objectives, while innovation provides the tools to achieve them. This relationship is crucial in engineering education, where addressing global challenges demands innovative solutions. Key gaps include fostering an innovation culture emphasizing critical thinking, ethical considerations, social responsibility, active learning methodologies, and effective integration of sustainability and innovation mindset in the outcomes to promote knowledge transfer capabilities. As a result, the design is a challenge-based learning framework that fosters an innovation mindset, nurturing a sustainability vision.

Keywords: student-centered approach; Engineering Education; Sustainability; Innovation.

1 Introduction

In the 21st century, global society faces the dual imperatives of sustainable development and innovation-led transformation. These challenges—exacerbated by environmental degradation, social inequalities, and shifting economic structures—demand a profound rethinking of how knowledge is generated, transferred, and applied. Education, particularly engineering education, is central to this process, as it equips the professionals responsible for shaping technical and infrastructural responses to societal needs. Integrating sustainability and innovation in engineering curricula has thus evolved from a desirable attribute to an urgent necessity.

Sustainability, initially confined to environmental concerns, is now widely recognized as a multidimensional framework encompassing ecological, social, and economic dimensions. Rooted in the Brundtland Commission's definition—"development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987)—the concept has broadened through the adoption of models such as the Triple Bottom Line and the Sustainable Development Goals (SDGs). These paradigms emphasize ethical awareness, long-term thinking, and cross-disciplinary collaboration. Consequently, education systems must promote cognitive knowledge and behavioral and affective competencies aligned with sustainability principles (Blanco-Portela et al., 2017; Wiek et al., 2011).

Simultaneously, innovation has emerged as a fundamental engine for economic and societal development. Schumpeter's (1934) early definition of innovation as "new combinations" of existing resources continues to influence contemporary understanding (Schumpeter, 1942), but has since been complemented by broader, systems-oriented approaches (Freeman, 2008). Today, innovation includes sustainable practices supported by models like design thinking, open innovation, and living labs (Berger et al., 1985; Chesbrough, 2002). These frameworks stress stakeholder co-creation, interdisciplinary work, and iterative learning processes. Tools such as Technology Readiness Levels (TRLs), Innovation Readiness Levels (IRLs), and Social Readiness Levels (SRLs) provide practical frameworks for evaluating innovation maturity and impact, underscoring the importance of systematic assessment in educational and professional domains (Tell & Hoveskog, 2022).

At the convergence of sustainability and innovation lies engineering education, a field uniquely equipped to contribute to sustainable transitions by designing and implementing technological solutions. However, traditional education models, with their emphasis on technical content delivery, may lack the depth required to address the complexity of contemporary global challenges of the contemporary world (UNESCO, 2022). As a response, higher education institutions are increasingly adopting student-centered approaches—such as Problem-Based Learning (PBL), Project-Based Learning (PjBL), and Challenge-Based Learning (CBL)—which promote experiential, collaborative, and ethical engagement with real-world problems (Sukacké et al., 2022). Among these, CBL has gained prominence for its explicit emphasis on systems thinking, ethical awareness, and the involvement of multiple stakeholders in the learning process (Tell & Hoveskog, 2022).

However, the implementation of such pedagogies remains inconsistent across global contexts. In Colombia, for example, while the number of higher education graduates has increased, employers continue to report difficulties in finding adequately skilled professionals, particularly in innovation-related areas (Colombian Private Competitiveness Council, 2023). This reveals a fundamental disconnect between the outcomes of higher education and labor market needs. The Global Innovation Index (WIPO, 2023) further highlights Colombia's slow growth in innovation metrics, attributing this to weak institutional frameworks and limited societal appropriation of knowledge. These trends are mirrored in other countries, underscoring the global nature of the challenge: educational systems are not sufficiently aligned with the evolving demands of a sustainability-driven innovation society.

Given this context, the central research question guiding this study is: How can the development of an innovation mindset be enhanced in engineering education from a sustainability perspective? Addressing this question requires curricular changes and a broader epistemological and cultural shift within educational institutions. It entails a movement from transmissive to transformative education, where students become co-creators of knowledge and meaning, capable of navigating complexity and uncertainty with creativity and ethical responsibility (Mezirow, 2000; Sterling, 2024).

This research advocates for a student-centered approach rooted in co-learning, in which students and educators engage in shared inquiry and collaborative problem-solving. Such environments foster technical and analytical skills, as well as the interpersonal and intrapersonal competencies necessary for sustainable innovation, including empathy, resilience, and systems thinking (Wiek & Lang, 2016). The model emphasizes learning experiences grounded in real-life challenges that reflect societal needs, encouraging students to develop solutions with a tangible and lasting impact (Schönach et al., 2023).

International reference institutions such as UNESCO, the OECD, and the Aalborg UNESCO Centre for PBL have promoted educational sustainability and innovation through policy recommendations, curriculum design, and teacher training (Kolmos & de Graaff, 2014; OECD, 2014). However, the results are present majorly in specific regions of the world. In some developed countries, many institutions lack the necessary resources, capacity,

and institutional will to adopt holistic, interdisciplinary, and transformative approaches to teaching and learning. Furthermore, the diversity of cultural, economic, and political contexts across countries necessitates flexible and context-sensitive models of educational transformation (Howlett et al., 2016).

This research addresses this need by adopting an integrative systems approach that combines educational theory and innovation metrics. It places particular emphasis on transforming student mindsets—toward sustainability-oriented innovation thinking—as a key outcome of reformed engineering education, contributing to the redefinition of engineering education as a catalyst for societal transformation. This entails adopting roles as facilitators, collaborators, and change agents—capable of leading sustainable innovation processes in diverse and dynamic contexts.

2 Methodology

The research will employ a mixed-methods and practice-oriented approach, incorporating qualitative and quantitative data collection techniques to capture the multifaceted nature of the learning process involving experimental interventions with engineering students. This process involves four stages: literature review, approach design, implementation and evaluation, and framework refining (Boud & Solomon, 2001; de Ven, 2007).

This work is in progress, specifically in the first stage, where was developed a systematic literature review (SLR) following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency, reproducibility, and reliability in analyzing innovation, sustainability, and engineering education (Page et al., 2021; Petticrew & Roberts, 2006). The methodology follows four stages: identification, screening, eligibility, and inclusion, enabling a structured approach to recognize research trends, gaps, and methodological insights (Boland et al., 2017).

A preliminary exploratory search was conducted using Google Scholar to define relevant keywords based on three core concepts of the groups: innovation, sustainability, and engineering education. The search equation was iteratively refined to align with the research questions:

- i. How has the academic discourse on innovation and sustainability within engineering education developed over the past decade, and what trends characterize this knowledge production?
- ii. Which student-centered pedagogical approaches and educational resources are most frequently implemented to foster innovation capabilities to address sustainability challenges in engineering education?
- iii. To what extent are innovation outcomes articulated in alignment with sustainability objectives in the reviewed literature, and how is this relationship conceptualized?
- iv. What are the dominant findings, insights, and implications drawn from the literature regarding integrating innovation and sustainability in engineering education?

Scopus and ERIC databases were selected for the formal search process. The search equation integrated key terms related to the three groups, focusing on publications from 2015 to 2024 to align with the 2030 agenda framework. The process identified 187 documents (138 from Scopus, 49 from ERIC). After temporal filtering, 34 papers were excluded. Additional exclusion criteria (duplicates, document type, and thematic relevance) reduced the dataset to 63 final sources: 25 from Scopus, 29 from ERIC, and 9 obtained through snowball sampling.

The study for selected literature considers a multi-level analysis approach, providing a structure to scaffold how the documents conceptualize innovation for sustainability in engineering education. It ensures a comprehensive understanding of its implementation across different scales of influence, as is depicted in Figure 1, which examines the results across three analytical levels: macro, meso, and micro (Courgeau, 2003).

At the macro level, the study investigates the interconnections between innovation, sustainability, and education in the selected literature. This level of analysis examines how overarching institutional and policy

frameworks impact the integration of sustainability into engineering curricula. The focus is on understanding how innovation culture and skill development contribute to sustainability-oriented education.

At the meso level, the analysis centers on how innovation supports sustainability through design approaches and resource efficiency in engineering education. This includes exploring curriculum transformation, adaptation, and the diffusion of best practices. Additionally, this level examines the role of student-centered pedagogies, particularly project-based and experiential learning, in preparing future engineers to address sustainability challenges.

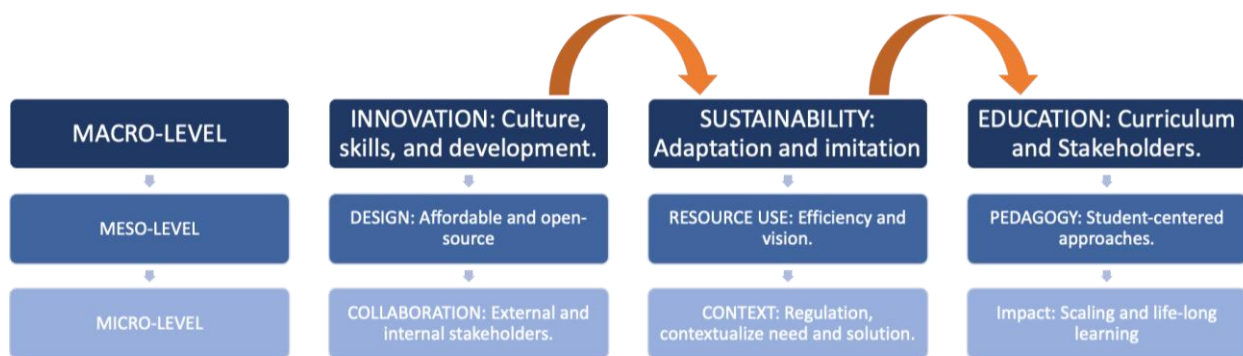


Figure 1. Methodological process

Finally, at the micro level, the study delves into specific themes and contextual factors influencing sustainability in engineering education. This includes analyzing technological adoption, industry-academia collaboration, experiential learning, and stakeholder engagement. The study also considers the importance of long-term impact, scalability, and ethical considerations, which are crucial in shaping effective and sustainable engineering education models.

3 Results

The study reveals how institutional culture, language, teaching practices, and contextual conditions shape the integration of sustainability vision into innovation in engineering education through a multi-level analysis, examining macro, meso, and micro levels.

At the macro level, a significant finding regards the institutional vision and national policy frameworks in defining the direction and scope of sustainability education. Universities that embed sustainability within their strategic objectives tend to foster a culture conducive to innovation and interdisciplinary collaboration (Georgallis & Bruijn, 2022; Küçüksayrac & Ariburun Kirca, 2020). However, a recurring challenge is the lack of a standardized language to articulate sustainability goals, which limits coherence across institutional and geographical boundaries (Persson et al., 2023). The fragmented use of terminology undermines knowledge transfer and creates barriers to curriculum alignment, particularly in international or collaborative educational programs (Sterling et al., 2018). This absence of a shared vocabulary hampers the development of a unified educational strategy for sustainability, which is critical for shaping innovation-oriented engineering graduates.

Skill development emerges as another macro-level concern, with several studies emphasizing the importance of cultivating transversal competencies such as systems thinking, ethical reasoning, and collaborative problem-solving. These skills are increasingly considered fundamental to sustainability education and linked to broader discourses on employability and innovation capacity (Blocker, 2023). Institutional efforts to develop such competencies are often shaped by external frameworks such as the United Nations Sustainable Development

Goals (SDGs). However, local interpretations of these frameworks vary (Georgallis & Bruijn, 2022; Persson et al., 2023).

At the meso level, curricular innovation is a mechanism for embedding sustainability in engineering education. Student-centered approaches are recurrently cited as effective strategies for fostering student engagement and developing sustainability-related skills (Pineda et al., 2024; Sonetti et al., 2019). However, successful implementation depends heavily on institutional culture and faculty readiness. Cultural resistance to interdisciplinary teaching and rigid departmental structures remains significant barriers (Moreno-Serna et al., 2022; Schönach et al., 2023). The literature highlights the need for structured faculty development programs that build educators' capacity to teach across disciplinary boundaries and adopt student-centered approaches (Amos & Levinson, 2019; Rekalde-Rodríguez et al., 2023).

Teacher training is an emerging issue that is becoming a growing demand for preparation in sustainability topics and student-centered approaches. This situation limits the depth and consistency of sustainability integration in engineering programs (Chen et al., 2019; Schönach et al., 2023). Several studies advocate for teacher education reforms that include sustainability-focused pedagogical frameworks, continuous professional development, and institutional incentives for interdisciplinary teaching (Das Neves et al., 2021; de Kraker et al., 2017). Moreover, the promotion of collaborative teaching cultures, where faculty from diverse disciplines co-develop and co-deliver sustainability content, is suggested as a strategy to overcome disciplinary silos and foster innovation (Egelund Holgaard et al., 2016).

At the micro level, the findings emphasize the influence of local context in shaping how sustainability is understood and implemented into innovation in engineering education. Factors such as regional sustainability challenges, institutional priorities, and stakeholder expectations all impact curriculum design and pedagogical choices (Howard et al., 2021; Murcott, 2016). The engagement of students and external partners in sustainability initiatives—through internships, service learning, or community projects—enhances relevance and deepens learning outcomes (Breen et al., 2023; Iyer-Raniga & Andamon, 2016). However, scalability remains challenging, particularly when such initiatives are resource-intensive or rely on individual champions.

In this context, language and discourse significantly shape pedagogical outcomes at the micro level. The way sustainability is framed within courses, learning outcomes, and institutional documents influences students' perceptions and pedagogical practices. Some studies suggest that overly technical or vague language can alienate students and obscure the ethical and societal dimensions of sustainability (Sierra et al., 2022; Sterling et al., 2018). Therefore, aligning language use with educational objectives and disciplinary norms is essential for fostering meaningful engagement.

Finally, ethical considerations and long-term impact are recurrent themes throughout the literature. Sustainable engineering education is not solely about technical competence but also about instilling a sense of social responsibility and environmental stewardship. These outcomes require sustained institutional commitment, flexible curricular models, and a willingness to adapt to evolving sustainability challenges (Sims et al., 2021; Wagner et al., 2021).

4 Concluding Remark

Empowering Engineers for Long-Term Societal Impact

The reviewed literature reflects a shared recognition of the urgent need to prepare engineering graduates for long-term engagement with sustainability challenges. While numerous pedagogical initiatives have introduced innovation and sustainability into the engineering classroom, empirical evidence regarding their enduring impact on students' professional practice remains limited. This underscores the need for longitudinal studies

that explore how graduates apply sustainability competencies in their careers and how educational institutions can better support this transition. Moreover, fostering self-awareness and mindset transformation is central to effective learning. Educational models should more explicitly integrate reflective practices, enabling students to internalize sustainability values and navigate ethical tensions inherent in engineering decisions.

Contextualizing Innovation through Language, Culture, and Stakeholder Synergy

Sustainability innovation could be interpreted through cultural, political, and institutional contexts. The literature reveals substantial variation in how sustainability is conceptualized and operationalized across regions and disciplines. A major barrier to implementation is the absence of a shared vocabulary and aligned long-term vision among stakeholders. Engineers, educators, industry leaders, and policymakers often operate within parallel discourses that limit collaboration and innovation diffusion. Addressing this fragmentation requires deliberate efforts to co-create a common language of sustainability—grounded in systems thinking, ethics, and cultural relevance.

Investing in Educators as Agents of Change

Educators are the linchpins of sustainability and innovation promotion in education, they demand training, institutional support, and pedagogical practice to lead them in their classrooms. Beyond technical expertise, teachers must adopt the role of facilitators and experts—mentors who guide students through complex, interdisciplinary problems with societal relevance—. This facilitative role enhances critical reflection, ethical reasoning, and collaborative problem-solving—skills essential for addressing sustainability challenges in engineering practice. To realize this potential, faculty development must become a strategic priority, moving beyond isolated training sessions toward sustained, context-sensitive support mechanisms embedded in institutional cultures.

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Artificial Intelligence in Engineering Learning: How Do Engineering Students Use It?

Ésoly M. Bento Santos¹, Denise Hirayama², Tiago Brandão Costa³

^{1, 2, 3} Federal University Fluminense, School of Industrial Metallurgical Engineering of Volta Redonda, Volta Redonda, Brazil

Email: esolysantos@id.uff.br, denisehirayama@id.uff.br, tiagobrandao@id.uff.br

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Abstract

Generative Artificial Intelligence (AI) is capable of creating texts, music, images, and programming code. These new pieces of information are generated based on learned patterns. Since then, several companies working in AI development have introduced various products to meet the demands of different fields, such as content creation, entertainment, and education. In the educational field, there has been extensive discussion about its use, addressing both its positive and negative aspects. This study aims to present the use of the NotebookLM AI, developed by Google Labs, as a pedagogical tool in engineering courses at the Fluminense Federal University in Brazil. The methodology combines active learning strategies with AI to enhance material curation in engineering courses. Students pre-select materials, use NotebookLM individually and in groups to answer questions provided during the activity, and participate in a collective discussion. The evaluation process considers knowledge acquisition, source selection, and engagement. Students used different types of materials to support their answers. However, the results indicate that the quality of the responses did not significantly vary based on the type of material chosen. The key factor influencing the quality of responses was the selection of materials with greater breadth and depth of content. An improvement in response quality was observed when comparing individual and group work. This advancement can be attributed to the refinement of strategies used in task execution. However, based on the professor's perceptions, students likely did not modify the responses generated by NotebookLM. This raises a fundamental question about the role of artificial intelligence in learning: did students use AI as a support tool, or did they simply delegate the responsibility of answering to it? Therefore, to make this activity more comprehensive, it would be beneficial to implement an individual assessment to verify its effectiveness in students' understanding of technical concepts.

Keywords: NotebookLM, Artificial Intelligence, Engineering Learning.

1 Introduction

Although the discussion around the use of Artificial Intelligence (AI) across various fields of knowledge has intensified recently especially since November 2022 with the emergence of large language model (LLM)-based chatbots such as ChatGPT, Gemini, and Meta.ai the dissemination of AI dates to the 1950s. As the use of these technologies has advanced, so have the concerns surrounding them. In this context, some educators and researchers have dedicated themselves to understanding and applying AI as a didactic resource (McCarthy, Minsky, Rochester, & Shannon, 1955; Nguyen, Ngo, Hong, Dang, & Nguyen, 2023).

In Brazil, a study conducted in 2024 by the Brazilian Association of Higher Education Institutions (ABMES) revealed that 71% of respondents use AI regularly, with 29% using it daily and 42% weekly. In just one year, the use of AI grew from 53% to 71% (ABMES, 2024).

Given this significant increase, it becomes essential to promote AI literacy among students, enabling them to understand and critically engage with these tools. A recent study showed that students felt more comfortable using AI after learning to understand and critically analyze its applications. The pedagogical approach involved collaborative practices using digital technologies, along with discussions, project creation, and presentations. Another teaching strategy described in the literature employed simulation-based learning. In this case, students explored different AI tools and systems (such as educational chatbots, virtual assistants, and virtual

reality simulations), which enhanced their understanding of real-life situations through immersive and interactive environments (Labrague, AL Sabei, & AL Yahyaei, 2025).

An AI tool with the potential to revolutionize education is NotebookLM, developed by Google. It adopts a research-centered approach, allowing users to efficiently organize, analyze, and synthesize information all within a practical and intuitive notebook-style interface (Google, 2025). Unlike the more popular AI tools such as ChatGPT and Gemini, NotebookLM does not function as a chatbot. Instead, it operates as a specialized tool for organizing documents and various sources, effectively acting as a virtual assistant for research and writing (Nieminen, 2024).

NotebookLM is a system that combines an advanced Large Language Model (LLM), capable of accurately understanding and generating text, with the Retrieval-Augmented Generation (RAG) technique. RAG enhances the LLM's responses by incorporating information extracted from an external database in this case, documents provided by the user. This allows NotebookLM to deliver accurate and personalized answers, reducing hallucinations and enabling source tracking, making it an ideal tool for education, research, and reliable data analysis (Tozuka et al., 2024).

To use NotebookLM, users must first upload the documents and research materials they wish to analyse. The platform supports various formats, including PDFs, text files (.txt), Google Docs, web links, copied text, and YouTube video transcripts. After the upload, NotebookLM identifies key information, highlights main themes, and establishes connections between different parts of the content. Based on this analysis, it generates a concise summary and offers various content formats, such as question lists, study guides, schedules, podcasts, and chat-based interaction (Huffman & Hutson, 2024).

NotebookLM has been used in education, benefiting both teachers and students in multiple ways. It assists in generating educational materials, significantly reducing the time needed for lesson preparation (Huffman & Hutson, 2024); enables the creation of conversational-style podcasts, allowing educators without technical expertise to edit high-quality audio an effective alternative for students who prefer auditory over textual content (Huffman & Hutson, 2024; Yeo, Moorhouse, & Wan, 2025); and facilitates research comprehension by helping students make connections, synthesize information, and gain insights from multiple sources, in addition to organizing content for research-based projects (Nieminen, 2024).

While several studies have focused on the use of AI-based chatbots, little has been discussed about the application of other tools such as NotebookLM. Therefore, this paper aims to explore the use of this technology in didactic practices within Engineering courses at a Brazilian university.

2 Methodology

This research adopts a descriptive and exploratory approach, focusing on the analysis of the use of Artificial Intelligence (AI) as a pedagogical tool in the teaching of concepts from the courses Thermoplastics Processing, Ceramic Materials Processing, and Applied Electricity. The study was conducted at the School of Industrial and Metallurgical Engineering of Volta Redonda (EIMVR). The activity was divided into different stages to ensure active and collaborative learning, as shown in Figure 1.

STEPS OF THE ACTIVITY USING NOTEBOOK LM

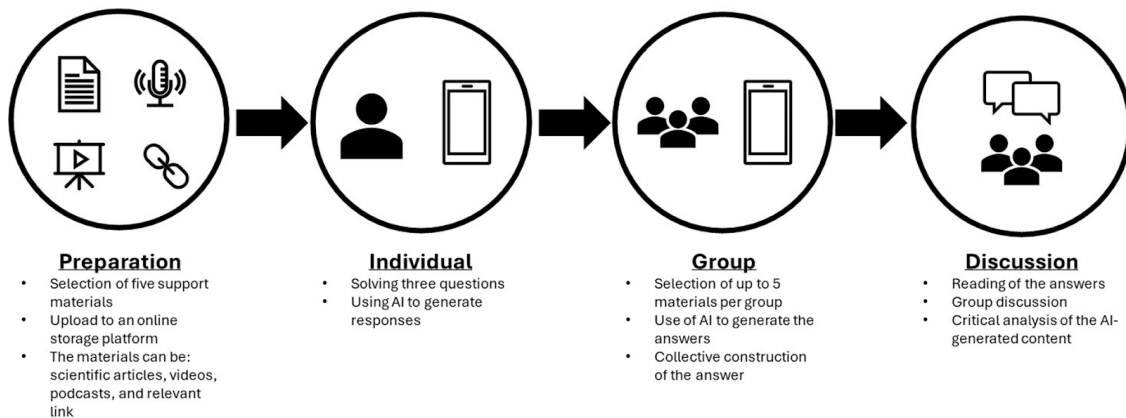


Figure 1. Stages of the activity using NotebookLM

2.1 Preparation for Activity

Students were instructed to conduct preliminary research on the topics covered in each course prior to the classes and were also informed about the learning objectives to be achieved. In the Applied Electricity course, students studied transformers, including their definition, types, components, operation, and applications. In the Thermoplastics Processing course, they explored FDM 3D printing, analysing its working principles and how printing parameters and material properties affect the final product. In the Ceramic Materials Processing course, students learned about the main ceramic forming methods, the effects of processing parameters on material properties, and the technical and environmental challenges of the sector.

Across all courses, students developed common skills such as curating research materials and critically analysing content generated by AI, in addition to adopting attitudes such as collaborative negotiation and individual responsibility. This approach fostered a comprehensive technical education that integrates specific knowledge with analytical skills and essential professional behaviours.

The selected supporting materials had to be uploaded to an online storage platform, with a limit of up to five items. These materials could include scientific articles, videos, podcasts, and relevant links. The main objective of this activity was to promote students' autonomy in curating reliable and relevant sources to support the proposed task.

2.2 Classroom Stage

Initially, students were introduced to the NotebookLM tool, and the guidelines for using artificial intelligence in the activity were discussed. Each student then individually answered the questions, using NotebookLM along with the supporting materials they had prepared. After this stage, students were organized into groups and collaboratively selected up to five support materials to be used with the AI tool. Together, they constructed a new, joint response, justifying their choice of sources. All materials produced, both individually and in groups, were submitted to the instructor. Finally, a discussion was held about the quality of the content generated by the AI, addressing areas for improvement and highlighting the importance of critically analysing the information provided. Students also completed a questionnaire about their participation, the method used, the skills and competencies developed and had the opportunity to leave suggestions for future activities.

2.3 Assessment

To grade students, assessments were based on specific criteria such as clarity, objectivity, and the relevance of the points addressed in relation to the topic. Grades ranged from 1 to 10, ensuring a precise and consistent evaluation. In assessing curatorial ability, the types, content, and languages of the support materials selected by the students were analyzed and compared to their grades to determine whether there was a relationship between the quality of their responses and the material chosen. A quantitative analysis was also conducted comparing the grades of individual work with those of group work. The questionnaire responses and the discussions held with students enabled an evaluation of the advantages and disadvantages of the applied methodology.

2.4 Professors' and Students' perceptions

The professors' perception was recorded through direct observation of the activity's development in the classroom, with notes on student engagement, interaction, and participation. Additionally, students were required to submit a written document containing the references used, the justification for their choice, and the resolution of the proposed task, which also contributed to the analysis of the effectiveness of the adopted approach. Complementing this perspective, students' perception of the methodology adopted in the activity was assessed through an online questionnaire created using Google Forms. The students answered questions about their experience with the classroom dynamics, enabling a qualitative and quantitative analysis of their collective impressions.

3 Results and Discussion

3.1 Professors' Perception

This study presents professor's perceptions regarding the curated materials used by students during the first stage of the activity, described as the individual task.

In the Thermoplastics Processing course, analysis of student performance revealed that those who scored highest (9.0 points) on the individual assessment demonstrated a diversified approach to information seeking. These students consulted different types of sources, including national and international articles, dissertations, theses, videos, websites, undergraduate theses, conference proceedings, and presentations. Although it was not possible to identify a specific type of material as decisive for better performance, the strategic selection of sources based on their breadth and depth was a distinguishing factor. Nevertheless, the overall average score for the individual activity was 8.5 points, indicating satisfactory performance by the class as a whole.

In the Ceramic Materials Processing course, a clear correlation was observed between the quality of the selected sources and the students' individual performance. The student who earned the highest score (9.0 points) used a 2020 review article, a 1990 book chapter regarded as a reference in the field, and other recent scientific papers. In contrast, a student who scored lower (7.0 points) cited older references, published between 2000 and 2007, along with an undergraduate research report and classroom support material. This suggests that selecting more in-depth and up-to-date materials significantly contributed to better academic performance.

In the Applied Electricity course, students who scored the highest on the individual assessment primarily relied on national articles, undergraduate theses, dissertations, and lecture notes. Notably, approximately 20 students used national articles, 25 referred to lecture notes, and 23 accessed theses or dissertations. This pattern indicates that sources offering a state-of-the-art overview tend to have a more developed theoretical

framework, which facilitates a better understanding of the topic and leads to higher evaluation scores. The average score for the individual activity was 8.0 points.

The findings show that the quality, diversity, and recency of sources played a fundamental role in students' performance on individual assessments. In all three courses, a common pattern emerged: students who sought more in-depth information such as scientific articles, book chapters, theses, and final papers achieved better results. The combined analysis of the three experiences reveals that strategic source selection, along with the ability to analyse and synthesize researched content, was crucial to success in the individual stage.

In the group activity stage, students' average scores improved, though the extent varied across courses. In the first case Thermoplastics Processing there was a modest 2% increase in the final average, raising it to 8.7 points. This gain was attributed to more efficient task strategies. Groups, already aware of the questions, selected more targeted materials, reducing redundancy and improving content comprehension.

In the Ceramic Materials Processing course, scores showed a more substantial increase of approximately 10%. This improvement was linked to the careful selection of references, with many groups relying on materials previously selected by the highest-performing individual student. Thus, sharing high-quality sources within the groups directly contributed to overall performance gains.

In the Applied Electricity course, the average increase was 5%, with final averages reaching 8.5 points. This improvement was associated with the greater opportunity for collaborative discussion on known questions and strategic material curation.

Overall, all three courses saw improved student performance in the group stage, driven by more deliberate source selection and the use of materials previously chosen by high-performing students in the individual phase.

Finally, the use of NotebookLM as an educational tool generated varying perceptions among professors, particularly regarding student autonomy in knowledge construction. Although all professors noted that students made few modifications to AI-generated responses, interpretations of this phenomenon differed, raising questions about the methodology's effectiveness in fostering meaningful learning.

A common observation among professors was that, in both individual and group activities, students tended to input information into the AI and accept the generated responses with minimal alteration. This raises concerns about the role of AI in the learning process: were students using NotebookLM as a complementary resource, or were they delegating the responsibility of knowledge construction entirely to the tool? This is a central question when assessing the methodology's true effectiveness. Nonetheless, this also highlights a broader concern regarding AI use in education. To achieve truly promising results, it is essential that students are guided in the appropriate use of such tools, developing their critical thinking skills when evaluating AI-generated responses. As (Bozkurt, et al., 2024) point out, AI in education should be linked to the promotion of critical thinking so that technology serves as a support rather than a substitute in the learning process.

Professors proposed several hypotheses to explain the lack of student authorship in their responses. Some suggested that students trusted the quality of their sources and assumed the AI's answers were correct and required no revision. Others noted that limited technical knowledge may have hindered students' ability to critically assess the generated content. Additionally, there may have been a communication gap, with students misunderstanding that the AI was meant to be a support tool rather than the primary source of their responses. These hypotheses align with the findings of (Modran, Chamunorwa, & Ursutiu, 2023 e Costa, Hirayama, & Santos, 2023), who emphasize that AI-generated responses should not be treated as definitive, but rather as supplemental information to support the learning process.

Despite these limitations, one positive aspect emerged: group responses showed slight improvement. This can be attributed to the fact that discussions among students encouraged a deeper reading of the selected materials, fostering more critical engagement. However, the lack of substantial modifications in the responses still suggests that the use of NotebookLM needs to be enhanced to ensure greater student involvement in the learning process. Thus, while NotebookLM shows potential as a didactic tool, its implementation requires refinement to ensure that students not only develop the ability to search for information but also the skills to analyse, question, and reframe it critically and autonomously.

3.2 Students' Perception

Based on the responses provided by the students, the effectiveness of the teaching method using NotebookLM was assessed in terms of participation, method efficiency, competencies, reflections, and suggestions. Regarding student participation, more than 80% adherence was observed in the courses analyzed. As for the effectiveness of the teaching method, the students who recognized the tool as beneficial for learning were the same ones who reported active participation in the activity. In the class with lower engagement, the perceived effectiveness of the method was also reduced. These data indicate a strong relationship between student participation and their perception of their own learning.

Although some authors suggest that behavioural participation may not have a direct influence on learning perception (Navarro, Vega, Bayona, Bernal, & Garcia, 2024), others have shown that different forms of engagement including interaction with AI and collaborative activities can influence how students perceive their learning process and the development of competencies (Tzirides et al., 2024; Labrague, AL Sabei, & AL Yahyaei, 2025), which is believed to have occurred in the context of these studies.

When considering the three dimensions of engagement: cognitive, emotional, and behavioural, it was found that students with higher cognitive involvement also demonstrated a deeper perception of learning, as they showed a strong intention to learn. Similarly, high levels of learning were observed among students who were emotionally connected to the activity. Another relevant factor is behavioural engagement, as students willing to put effort into completing activities tend to achieve more positive results (Navarro, Vega, Bayona, Bernal, & Garcia, 2024).

When analysing the competencies perceived by students, teamwork stood out, identified by more than 80% of participants.

Understanding and problem-solving were mentioned by more than 60% of students. These competencies had already been discussed by other authors, and their development is fundamental as it allows students to learn from each other, share different perspectives, and build knowledge collaboratively (Labrague, AL Sabei, & AL Yahyaei, 2025).

Competencies such as proactivity, entrepreneurship, and innovation were mentioned exclusively by students of Applied Electricity and Ceramic Materials Processing, while leadership was identified only by students in the Applied Electricity course.

In addition to the competencies initially evaluated, students also highlighted skills not suggested by the professors in the survey, such as the use of new technologies with emphasis on artificial intelligence (AI) highlighting an emerging demand for knowledge related to digital tools in academic and professional contexts. Some authors emphasize that competence in the use of AI has become increasingly significant in various professional settings, as developing this competence prepares students for their future careers (Labrague, AL Sabei, & AL Yahyaei, 2025).

Although some students initially had a negative perception of using AI as a support tool, many came to recognize it as an important resource in the teaching-learning process, when used appropriately. Some statements also show how the activity sparked curiosity and engagement with the topic, as in the following comments: "I was surprised to discover that there is an AI for which I create the database," and "I thought using Google involved reading articles, but it turned out to be a lesson about the NotebookLM AI."

There is clear evidence of appreciation for the development of digital competencies, as revealed in the following statement: "The information about the AI tool made me curious about how important it is to select the right sources, and that led me to reconsider the articles I chose."

This type of reflection highlights progress in critical thinking, as students recognize the importance of source quality.

Although the professors expected the use of the tool to promote an even deeper level of reflection, it is undeniable that there were, in fact, signs of critical thinking among the students. However, the development of this analytical posture still needs to be encouraged in a more structured way in order to enhance student agency in the use of digital technologies.

4 Conclusion

This study investigated the use of NotebookLM in instructional practices within engineering courses at a Brazilian university. The findings reveal that students did not engage with artificial intelligence merely as a support tool. In practice, most students tended to adopt the AI-generated responses with minimal modifications. The instructional design anticipated that AI would serve as a starting point to foster critical thinking and autonomous knowledge construction. Students were expected to critically analyze, question, and reformulate the content provided by the tool based on their own reasoning. However, the results suggest that this more reflective and critical engagement with AI still requires further encouragement and development among the participants.

The outcomes of the activity raise an important question: did students genuinely learn during the process? With regard to the technical content addressed through AI, the design of the activity did not yield concrete evidence of deep learning. In most cases, the responses submitted by students were direct reproductions of AI outputs, lacking elaboration or conceptual depth. Classroom discussions were limited to reading the generated responses, with little indication of independent argumentation or critical understanding. From the professors' perspective, there were no clear signs of sustained assimilation of content throughout the course following the activity.

Nevertheless, it would be inaccurate to conclude that students acquired no learning during the process. On the contrary, they demonstrated meaningful progress in their interaction with artificial intelligence. Students exhibited increased engagement with the tool, exploring its functionalities, questioning its mechanisms, uploading various file types, and collaborating in curating the input materials for the AI. These behaviours reflect the development of skills in the psychomotor and affective domains, particularly in terms of technological proficiency and collaborative learning. Thus, while cognitive gains related to conceptual content may have been limited, the activity contributed to other significant dimensions of the educational process.

In the specific case of NotebookLM which generates responses exclusively from user-provided material students expressed greater confidence in the outputs, as the reference material had been selected by themselves. This appeared to reduce concerns about incorrect answers and fostered a stronger sense of reliability and trust in the generated information. Students felt more comfortable engaging with the tool, given

the assurance that the AI would not "hallucinate" or produce information disconnected from the curated knowledge base.

It is essential to emphasize, however, that artificial intelligence must be understood as a resource to support critical analysis, rather than a source of ready-made or definitive answers. Its integration into educational settings should serve to stimulate inquiry, critical reflection, and the construction of knowledge, not to substitute these core learning processes.

Based on these reflections, the instructional team proposes methodological adjustments aimed at reinforcing students' active participation. One potential strategy is the implementation of individual assessments following the activity to verify assimilation of technical concepts. Furthermore, it is imperative to promote artificial intelligence literacy, enabling students to adopt a critical stance toward technological tools and to recognize that, regardless of the resource employed, the learning process must remain student-centered and inquiry-driven.

Finally, the study contributes to the discussion on artificial intelligence literacy as a transversal competency required in engineering, reinforcing the idea that future engineers must be prepared not only to use AI, but also to understand it, critically evaluate it, and integrate it ethically and responsibly into their professional practice.

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Across the *axes*: Faculty Perceptions of Professional Development Programmes in Higher Education

Maitê Gil¹, Rita Tavares de Sousa²

¹ Universidade Católica Portuguesa, Research Centre for Human Development, Porto, Portugal

² Universidade Católica Portuguesa, Centre for Research and Intervention in Education, Research Centre for Human Development, Porto, Portugal

Email: mmgil@ucp.pt, rrsousa@ucp.pt

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Abstract

Faculty professional development is a multifaceted process involving various models of continuing education; it benefits from a combination of practices that foster professional autonomy and transformative learning. Formal programmes typically include structured workshops and courses, while their impact depends on their relevance to faculty teaching contexts. However, informal activities, such as peer conversations, also play a significant role in faculty learning. Thus, the literature shows that a balanced approach that blends formal and informal methods, transmissive and transformative actions, creates a more effective professional development agenda. In this context, this paper presents an exploratory case study assessing faculty members' perceptions of the different possibilities regarding professional development in Higher Education. Data was collected through semi-structured interviews with three teachers identified as key participants, as they are highly committed to their professional development, regularly taking part in a variety of training activities. The findings reveal that participants valued activities spanning the formal-informal and transmissive-transformative axes. However, their perspectives on the initiatives were shaped by two lenses: the specific characteristics of each initiative in terms of form and purpose and the profile of the teacher.

Keywords: Professional Development; Higher Education; Faculty Perceptions; Project Approaches.

1 Introduction

Effective professional learning is not necessarily limited to intentional development opportunities and activities, such as workshops or courses, but it is rather often 'situated' (Lave & Wenger, 1991) and often occurs implicitly (Eraut, 2004; Evans, 2019), in sometimes unanticipated ways, through social interaction (Evans, 2025). According to Clarke and Hollingsworth 'if we are to facilitate the professional development of teachers, we must understand the process by which teachers grow professionally and the conditions that support and promote that growth' (2002, p. 947). It is also important to have clear definition of what professional development means. Some perspectives reduce professional development activities to those which are tangible and visible and/or have a direct impact on students' outcomes. However, although it may have secondary beneficiaries (namely students), professional development conceptualisations or definitions should not be reduced to this dimension (Evans, 2019).

Given this underlying complexity, identifying faculty members' interests while seeking professional development initiatives, as well as the potential of the different possible forms and models of development, is therefore relevant to the design of evidence-based professional development programmes. In this context, we carried out an exploratory case study aiming at assessing faculty members' perceptions of different possibilities regarding professional development in Higher Education. The following sections introduce a quadrant, developed specifically for this study, to analyse faculty professional development, along with the axes that underpin it. Section 3 outlines the methodology, while Section 4 presents the results. The final sections offer a discussion of the findings and concluding remarks.

2 A Quadrant for Faculty Professional Development

Research indicate that faculty professional development is a dynamic process that encompasses a range of continuing professional development actions rather than following a single path (Kennedy, 2014; Evans, 2019; Smith & Wyness, 2024, among others). According to Middlewood and colleagues (2005) professional development can be perceived as an ongoing process of reflection and review that articulates with development planning that meets corporate, departmental and individual needs.

Smith and Wyness (2024) explored the diversity of professional development in Higher Education across 13 different international perspectives. The authors developed a systematised literature review, revealing that the composition, the design and the purpose of professional development for faculty is diverse in many aspects. Their results highlight some of the key-characteristics to be considered in professional development programmes, namely: Relatability; meaningfulness; appropriate design for the transfer of learning from theory to practice; flexibility; voluntariness; and realistic feasibility for teacher attendance. Accordingly, the authors suggest that “professional development is perceived to be more valuable when it is flexible, informal and structured in its design” (Smith & Wyness, 2024, p.18).

Considering the three features identified by Smith and Wyness (2024) (i.e. flexibility, (in)formality and structure), we propose, for this study, a framework for analysing faculty professional development, structured around two axes: formal/informal and transmissive/transformative (Figure 1 – left side). Considering the two structuring axes of the suggested quadrant, teacher professional development initiatives can be allocated to different points, considering the strictness of their structure and the nature of their purpose. Given the key characteristics of each axis, described in the following sections, Figure 1 (right side) shows an initial proposal for allocating the different activities in the quadrant. This distribution is illustrative and not intended as a final or immutable arrangement; rather, it serves as a baseline for the semi-structured interviews conducted in this study. Figure 1, while part of the literature review, stands as a contribution in its own by reflecting the authors’ interpretation and organisation of existing work.

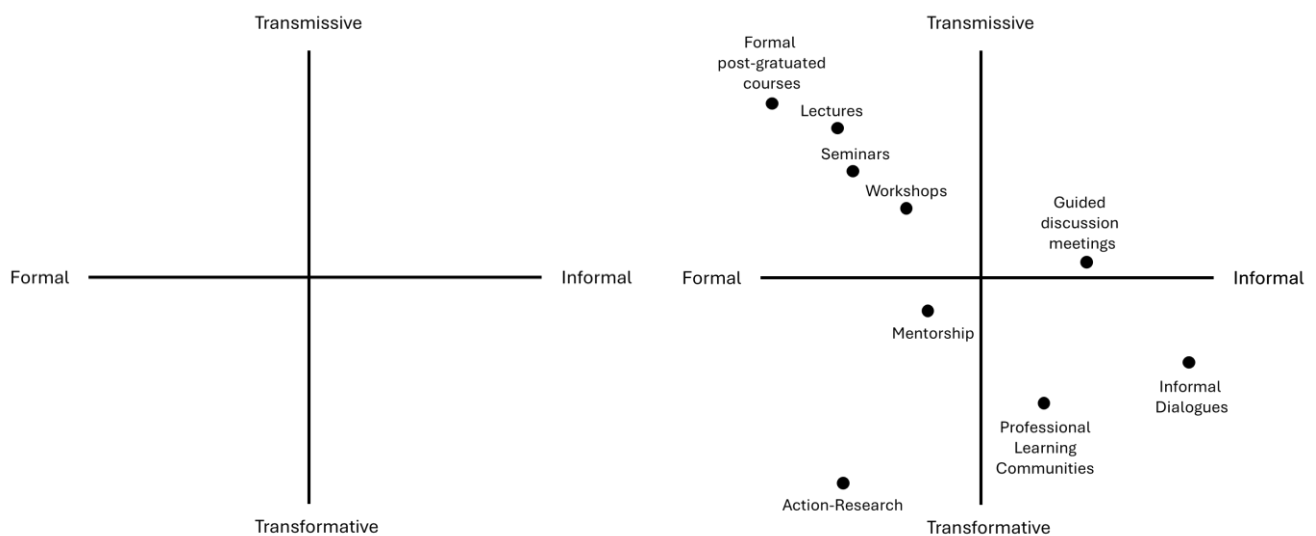


Figure 1. A Quadrant for Faculty Professional Development (left side) and an initial proposal for allocating the different initiatives in the quadrant

2.1 The formal-informal axis

According to Friedman and Philips (2004, p. 369) the legitimacy of professional development activities is often perceived of in terms of formal training courses linked to work gaining a qualification - portable and bankable. However, learning may occur in many different sets and formats, encompassing a whole range of activities

from formal to informal: formal courses, seminars, workshops, mentorship, peer learning, co-planning, online training, communities of practice, and so on.

By framing professional development as existing along a continuum of formal-informal (Eraut, 2004; Evans, 2019), rather than as a binary of formal versus informal activities it is possible to acknowledge that professional development activities can have characteristics of both, and that professionals engage in a mix of learning experiences. Looking at professional development in this continuum implies having a clear notion of what counts as formal and informal activities of professional development. Forms of informal professional learning and development are those which

are not explicitly labelled or signposted as such, and which are consequently in danger of slipping under the radar of consideration of how people develop professionally. These forms include what is referred to as “implicit” (professional) learning or development, and which I am inclined to interpret as occurring without the learner’s or developpee’s awareness or consciousness of her/his learning or development. (Evans, 2019, p. 6)

Unlike formal learning, informal learning requires teachers to develop self-regulated learning skills, have an authentic need or internal motivation, and be offered sources for collaborative learning (Avidov-Ungar et al., 2023; Dubovi & Tabak 2020). In fact, formal professional development opportunities often focus on teaching tools, knowledge and strategies, but teacher may also have social, affective, and identity needs to be met which can be addressed by informal professional development activities (Avidov-Ungar et al., 2023). In this sense, it is possible to state that formal professional development tends to be structured, planned, and often externally mandated (e.g., workshops, training sessions, accredited courses), while informal professional development activities are more organic, self-directed, and integrated into everyday practice (e.g., collegial and informal conversations, online forums, communities of practice).

2.2 The transmissive-transformative axis

Another important way of understanding professional development is by considering the purpose of the initiatives. In this concern, Kennedy (2005; 2014) presents a framework for analysing continuing professional development models according to their goals, positioning the initiatives along a continuum that ranges from ‘transmissive’ to ‘transitional’ and ultimately to ‘transformative’. In this framework, the models are classified sequentially against the capacity for supporting teachers’ autonomy and agency. Within this context, agency – i.e, teachers’ capacity to make choices, take actions, and enact changes – is considered a central ability to teachers successfully perform their professional roles, pursuing what they value in their practice (Molla & Nolan, 2020).

The initiatives categorized as transmissive focus on teacher development through expert-led instruction, usually targeting technical aspects of the job rather than issues relating to values, beliefs and attitudes. Some examples are the training, the award-bearing and the cascade model. Within transitional models, the initiatives have the potential to align with either a transmissive or a transformative agenda. Approaches typically situated within this category include coaching and mentoring, as well as communities of practice. Finally, the transformative models present a robust relationship between theory and practice. These models aim at supporting professional autonomy and agency, focusing on the assimilation of concepts, the engagement in reflective practice, the construction of new knowledge and its application across diverse contexts (Kennedy, 2005; 2014). Besides, transformative models that support teacher agency necessitates (a) creating an empowering learning environment, and (b) problematising professional practices (Molla & Nolan, 2020).

In the transmissive-transformative spectrum, although different types of models/initiatives are arranged as a continuum of discrete categories, these may not be mutually exclusive (Boylan et al., 2023). That is, instead of

advocating for one or the other, research shows that a transformative professional development agenda is supported by combining diverse practices and conditions (Kennedy, 2014).

3 An Exploratory Case Study on Faculty Perceptions

Considering the exploratory nature of this study, we developed a qualitative case study. We understand a qualitative case study as 'an in-depth description and analysis of a bounded system' (Merriam, 2009, p. 43), which has characteristics in line with the aim of this investigation, namely: (i) it is used to search for meaning and understanding; (ii) the researcher is the primary instrument of data collection and analysis; (iii) it is an inductive investigative strategy; and (iv) the end product is richly descriptive (Merriam, 2009).

As data collection strategy to assess faculty members' perceptions, semi-structured interviews were conducted with three teachers highly committed to their professional development. All of them regularly take part in a variety of training activities (more than four times a year), leading them to be identified as key participants to this study. However, we acknowledge that the fact that all participants are highly committed to professional development might bias perceptions toward more transformative and varied experiences. Their experience in higher education is very diverse, varying from "up to 5 years" to "more than 20 years". All ethical aspects were considered with participants giving them consent to participate. Their confidentiality and anonymity were guaranteed.

The interviews were guided by a previously drawn-up script and conducted by the two researchers. The focus of the interactions was their experiences and perceptions about professional development programmes. Although the questions were open-ended, they carried an underlying assumption about the initial distribution of the different professional development initiatives within the quadrant (Figure 1), informed by the theoretical framework presented. The interviews took place online. The data were recorded and transcribed; then analysed by the authors utilizing the support of NVivo Software (version 15). It was employed the thematic analysis method (Braun & Clarke, 2006), taking the thematic oriented segments as the analytical unit. Each author has done a floating reading of the data independently and then met to discuss and define the final categories and hierarchy. All authors were involved in the coding and querying phases to analyse the qualitative data and draw evidence-based conclusions systematically. Given the purpose of this study, the excerpts were categorised according to the participants' point of view (i.e, even though the workshops were allocated towards the transmissive pole in the initially suggested distribution, they were classified as transformative when the participants described them in this way). The excerpts were included in more than one category when they were connected to both.

4 Results: How do teachers experience and perceive their professional development?

The data analysis uncovered three central categories to the understanding of the faculty members' perceptions on professional development, namely: (i) Motivations, which is related to what motivates teachers to engage in professional development activities; (ii) Reflection on the structure of the activities, which refers to explicit considerations regarding the activities formats; and (iii) Perceived effects, which refers to the perceived impact of the experiences. Table1 shows the coding system generated from the data analysis; the numbers in brackets indicate the number of references associated to each category and subcategory identified in the dataset.

Table 1. Hierarchy Table of the Coding

Category	Subcategory	Description
Motivation (15)	Practices' improvement (7)	Excerpts related to the aim of increasing the repertoire of practices or learning more about the implementation of any methodology/approach.
	Practices' Validation (6)	Excerpts related to the aim of finding ways to evaluate their own practices or validating their practice through peer-feedback.
	Theoretical learning (2)	Excerpts related to the aim of learning more about methodology/approach or finding references to inform their practice.
Reflection on the structure of the activities (27)	Formal (12)	Excerpts related to well-structured activities of professional development.
	Informal (15)	Excerpts related to non-structured activities of professional development.
Perceived effects (18)	Transmissive (1)	Excerpts that mention improvements on technical aspects of the job.
	Transformative (17)	Excerpts that mention improvements on professional autonomy and agency (i.e., engagement in reflective practice; construction and/or application of new knowledge)

Participants have indicated three main motivations to join professional development activities: To improve their teaching practices, to evaluate and/or validate their practices and to learn theory. Regarding improving their teaching practices, participants highlighted the need to enhance or refine the strategies and methods they already use, as well as the need to adapt their teaching strategies according to their students' profiles and contemporary challenges: *'[I look for] the improvement in the way I teach, some new ideas, also because the changes happen so quickly [...]' (Marianne)*. Another motivation is related with evaluating and/or validating their practices, in which professional development opportunities are perceived as a space for self-reflection, but also for confirmation their approaches effectiveness: *'and also looking for, how can I say it?, there are some practices that you intuitively adopt and you want to realise how they can be theoretically supported and also know if there is evidence related to them or not.'* (Marianne). The motivation to learn new theories is based on the strong belief that a good practice is grounded in solid theory. In this sense, participants are motivated to find theoretical models that support their pedagogical decisions, to update their knowledge and some also express an interest in conducting research regarding their own pedagogical practices: *'usually I participate [in professional development activities] to check something that I do not know yet, because the knowledge keeps increasing and I do not have time to read everything' (Amy); 'And, for example, one of the things I feel the need to do is research my own practice' (Emily).*

When reflecting on the structure of the professional development activities, participants have recognized characteristics and contributions of formal and well-structured activities and informal and non-structured activities of professional development. It is important to refer that the participants do not engage exclusively in one or the other but move across the continuum of formal-informal professional development activities. Formal professional development activities are related with getting new information, practical orientation and allowing an immediate applicability: *'In other words, many things are actually about absorbing information and then appropriating it or not in the daily practice of teaching' (Marianne)*. This kind of activities sometimes challenges participants, since they could imply experiencing new things: *'I think that there are different things, and sometimes the activities with more structure also put me in an uncomfortable position. Why? Because I need to practice a series of things that sometimes I would prefer not to do.'* (Emily). Informal activities are characterized

by spontaneity, flexibility, and peer interaction often occurring in daily routines: *'during the lunch time or during the commuting – sometimes I give a ride to a colleague – we talk and I have many ideas with our conversations' (Marianne)*. The collaboration and sharing of practices are aspects that characterise informal activities of professional development and have a positive impact: *'but we are going to think together, we are going to look at our things, we are going to produce, we usually also have interesting outcomes that result from this sharing [among peers], from this joint reflection and, therefore, what we bring are, in essence, good practices' (Amy)*.

Finally, participants referred to perceived effects of the professional development activities mainly regarding improvements on their professional practice, which occur due to something they learned or had the opportunity to reflect on: *'often we come up with an idea that we can also implement and, for example, the last time I took part [in a course] and changed a project, I was doing one workshop (...) and I had ideas for short active learning strategies, so [...] I end up introducing a more dynamic moment in the class.'* (Amy). Also, being involved in different activities (in purpose, nature, structure) of professional development allow for new ways of thinking and making connections, improving teachers' agency for choosing what suits best: *'Sometimes it's opening avenues in my brain. It's almost like being permeable to things and then, because I participate in those things, I make associations' (Emily)*.

5 Discussion: The quadrant reading lenses

These results lead to some relevant considerations regarding the design of professional development activities. First, the predominance of motivations directed primarily towards practice may be understood as a reflection of the teachers' concern with the dimension of teaching. This pattern may suggest that their engagement with professional development is closely tied to the immediate demands of their educational context, rather than abstract or theoretical pursuits. This result reinforces the need for appropriate design regarding the transfer of learning from theory to practice, highlighted by Smith and Wyness (2024).

Second, the variety of mentions regarding the different structural possibilities of professional development activities highlights teachers' intense engagement with a broad spectrum of practices. This diversity confirms that their experiences are not confined to a single approach to professional development but are instead informed by an intense contact with various kinds of activities. This exposure may foster a more flexible and adaptive understanding of professional development, enabling teachers to navigate and integrate multiple activities according to their personal and contextual needs.

Third, the presence of only a single reference to transmissive experiences may be linked to the fact that the interviewed teachers are active participants in professional development programmes. This behaviour reinforces the argument presented in the literature, where it is acknowledged that although different models and initiatives can be arranged along a continuum of discrete categories, these are not mutually exclusive (Boylan et al., 2023). As highlighted before, research demonstrates that a transformative professional development agenda benefits from combining diverse practices and conditions (Kennedy, 2014). It seems that the vast experience of the three teachers in professional development activities is reflected in the scarcity of transmissive references, that is, their commitment to their professional development has made them proficient at reflecting on their practices and beliefs and able to implement changes more autonomously, regardless of the nature of the activities they take part in.

Considering the aim of assessing faculty members' perceptions of different possibilities regarding professional development in Higher Education, this study reveals that there are highly specific factors related both to the design of each professional development activity (i.e., two workshops may be structured in very different ways) and to the individual characteristics of each participant (i.e., kind and intensity of prior experiences) that may

significantly influence one's experience with and perception on the same activity. Therefore, two lenses are needed to allocate the different professional development activities in the quadrant proposed in this study: the specific characteristics of each initiative in terms of form and purpose; and the profile of the teacher (Figure 2).

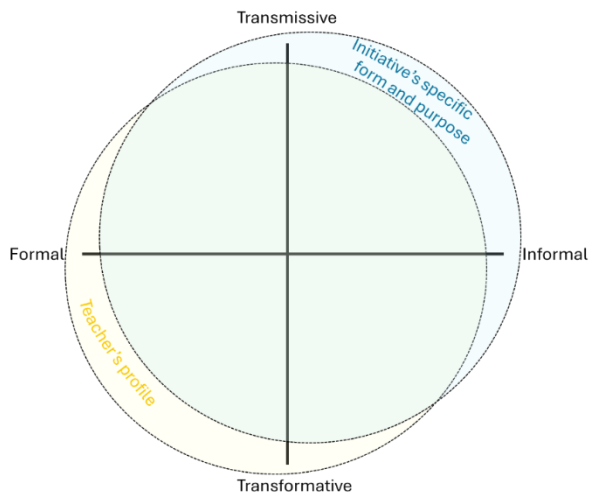


Figure 2. The Quadrant for Faculty Professional Development reading lenses

6 Conclusion: Insights for Faculty Professional Development

The complexity of the faculty professional development spectrum is based not only on the different possibilities associated with the design of the initiatives (i.e. their purposes, formats, structure, etc.), but also on the different individual characteristics, experiences, and dispositions that comprise the profile of each teacher. This interaction between the two levels (or lenses) generates so many possibilities, revealing that each process is unique. The common aspect seems to be looking for what Evans (2019; 2025) calls a 'better way' of doing things. The recognition of something as a 'better way' may occur because of a deliberate search, when an individual is dissatisfied with her/his practice and seeks improvement, but it can also occur without having been sought and without any prior recognition of deficit. However, despite what led to this 'better way', professional development activities may 'be considered dependent upon this (usually unconscious) process of comparison (between the new, "better", element of practice and what it replaces)' (Evans, 2025, p.10). In this sense, this study highlights the need to adopt two complementary lenses when designing and evaluating professional development programmes: the form and purpose of the initiative itself, and the profile of the teacher engaging with it. Each lens contributes uniquely to how the same activity can be interpreted and experienced – what may be transformative for one teacher may be perceived as transmissive or ineffective for another.

This dual perspective may carry important challenging implications for those responsible for designing and implementing professional development programmes, but it also open new paths. Rather than focusing solely on producing 'ideal' activities, institutions should consider creating diverse, flexible opportunities with a common thread: to intentionally approach the different initiatives in an articulated way, so that each teacher can be an agent of their own development process.

Despite being exploratory in nature, this study provides a conceptual framework and empirical foundation for further investigation. However, it presents some limitations, namely the small number of interviews and the relatively homogeneous profile of the participants. Including professionals who are less engaged in

professional development activities could reveal different behaviour patterns and perspectives. Moreover, applying this framework to a larger and more diverse sample could yield more nuanced patterns, supporting the development of more tailored professional development strategies. For future research, expanding the sample size would be beneficial. Additionally, asking teachers to "fill in" the analytical framework quadrants based on their own experiences could help identify how similar or identical activities are perceived differently. This would allow for a deeper evaluation of how the two theoretical lenses operate in practice. Future studies may also explore how different institutional cultures, or disciplinary fields influence teachers' positioning within the quadrant. As institutions strive to foster teaching excellence, acknowledging the subjective, context-dependent nature of professional learning may prove essential for truly impactful development programmes.

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Enhancing Student Engagement and Assessment

Ana Paula Nolasco¹, Maria Paula Oliveira², Paolo Vettori³

¹ Universidade de Aveiro, Department of Mathematics, Aveiro, Portugal

^{2,3} Universidade de Aveiro, Department of Mathematics, Center for Research & Development in Mathematics and Applications, Aveiro, Portugal

Email: anolasco@ua.pt, paula.oliveira@ua.pt, pvettori@ua.pt

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Abstract

In engineering education, fostering active student engagement and effective assessment strategies is crucial for enhancing learning outcomes. This study explores innovative teaching and assessment methods implemented in engineering courses involving around 500 students across multiple engineering degree programs. To promote active learning, we incorporated peer assessment and collaborative group work, where students completed structured tasks evaluated through detailed rubrics. In theoretical classes, we introduced Vevox, an interactive response system, to increase student participation and comprehension. Additionally, board games were integrated into selected topics to enhance conceptual understanding through gamification. Assessment methods were diversified to ensure comprehensive evaluation. Throughout the semester, students completed online tests via Moodle, allowing for continuous assessment and immediate feedback. A final written examination was conducted at the end of the term to assess overall knowledge retention and application. The impact of these strategies was measured by comparing student performance with the previous academic year. Results indicate a significant improvement, with an increase of 14% in the number of approved students. Feedback from students highlighted increased motivation, deeper understanding of theoretical concepts, and greater engagement with course material. These findings demonstrate that a combination of interactive learning tools, peer assessment, and varied evaluation methods can significantly enhance engineering education. This study provides some insights for educators seeking to implement innovative approaches that foster deeper learning and improve student outcomes in STEM disciplines.

Keywords: active-learning, calculus, peer-assessment, gamification.

1 Introduction

Active learning prepares students for the challenges of the future by equipping them with the skills and competencies needed in the modern workforce. Employers increasingly value graduates who can think critically, solve complex problems, and work effectively in teams. By incorporating active learning strategies into university curricula, educators can help students develop these essential skills and better prepare them for their future careers. A definition of active learning is given in (Freeman, et al., 2014) "Active learning engages students in the process of learning through activities and/or discussion in class, as opposed to passively listening to an expert. It emphasizes higher-order thinking and often involves group work."

Being Calculus a first year and first semester curricular unit for science and engineering students, it is a good starting point to shift the way students learn and collaborate. In this paper we will present the strategies used to engage students and discuss the results of this practice.

Moodle is the Learning Management System used in University of Aveiro. It has a great potential to work with active learning methodologies, namely submitting and classifying group work, peer assessment tools, bank of questions that can be reused, the facility of creating online tests, of communicating, etc. These features, along with its generalised use in our university, made us choose it as the communication platform in our course.

In the first class of the semester, we explained to the students how the Calculus course would work, what was expected of them, and most importantly, we justified the importance of the methods we would use.

We could define three fundamental axes of the methodology used: Communication, not only mathematical communication; Assessment and Learning activities.

To promote communication between students, group work was implemented along 12 sessions during the semester. It is our belief that “the more time students spend working in groups, the more favourable their learning-related attitudes become” (Springer, Stanne, & Donovan, 1999).

The same authors support that “The rationale for implementing group goals is that, if students value the success of the group, they will encourage and help one another to achieve” (Springer, Stanne, & Donovan, 1999).

Assessment is the thickest axe, because most students fight for the grades, although with different targets: just approval or the best grades in class.

Assessment is the making of judgements about how students’ work meets appropriate standards. Teachers, markers and examiners have traditionally been charged with that responsibility. However, students themselves need to develop the capacity to make judgements about both their own work and that of others in order to become effective continuing learners and practitioners.

As referred in (Boud, 2010),

- assessment should be used to engage students in productive learning;
- feedback should be used to actively improve student learning;
- students and teachers become responsible partners in learning and assessment;
- students should be involved in assessment practices;
- learning assessment should be placed at the heart of subject conception and programme design;
- learning assessment should promote institutional and individual development;
- assessment should provide an inclusive and reliable representation of student performance.

These principles were the drivers of the assessment process we designed.

An example of learning activities developed in our Calculus course was the use of instructional board games, as they can be a powerful tool in mathematics teaching for university students. They offer a dynamic and engaging way to explore complex mathematical concepts, fostering both understanding and retention.

In section 2 we will describe in detail the instruments used along the course and in section 3 we will focus on discussion of results compared with previous academic years.

2 Methods

At the University of Aveiro, Calculus is part of the curriculum of almost all the sciences and engineering degrees, but students are enrolled on different Calculus courses: our unit has around 500 students from Physics, Biomedical Engineering, Computational Engineering, Physical Engineering, Meteorology, Oceanography, and Climate, Materials Engineering, Industrial Engineering and Management and Mechanical Engineering.

Our Calculus course has four weekly contact hours divided into two blocks of two hours each. These hours were used to discuss the theoretical concepts relevant to the course, supplemented with examples and one or two in-class exercises (2 hours, usually 1 hour in each lecture); to do group work, where the teacher acted as a guide (1 hour) and address student queries and clarify issues identified in the previously submitted group work (1 hour).

To make the lectures more dynamic and interactive, especially when discussing or presenting new concepts, we utilized Vevox for posing questions to students, whose responses were then discussed collectively.

Having in mind that this is a first year, first semester curricular unit, students were explained the objectives of the course, beginning with the non-mathematical ones: promote relationships among students; encourage group work, embracing differences; develop work habits both inside and outside the classroom; foster healthy discussions among students and between students and teachers and hold each student accountable for their own learning.

They were also told that they would integrate three different groups throughout the semester, randomly formed using a Moodle tool. This approach promotes interaction with various peers, fostering a crucial skill for future professional life.

In the following we describe the various components of the course.

2.1 Working in groups

Working in groups helps students develop stronger communication skills, as they need to explain their ideas, listen to others and provide feedback.

Weekly, students completed a group task (each group had different tasks but with the same educational content) on the topics covered in that class and/or the previous class. These tasks were submitted on Moodle at the end of the class for evaluation by the teacher. An example of a submitted task is in Figure 1.

Cálculo I - B		TPA11-E	2024/25
Critérios da razão, da raiz e de Leibniz. Séries de Potências			
Indicar a turma TPB- e o grupo G- e preencher com os dados dos elementos do grupo presentes:			
Papel atribuído	N.º Mec.	Nome	
Gestor/Portavoz			
Escriba/Carteiro			
Colaborador			
Colaborador			
Colaborador			
Colaborador			
Colaborador			
Colaborador			

Antes de o anexar, verificar que o ficheiro PDF tem boa qualidade!

- Estuda a natureza da série $\sum_{n=0}^{+\infty} \frac{(-3)^n}{1+n3^n}$ e, caso seja convergente, especifica se simples ou absolutamente.
- Determina, em função do parâmetro α , a natureza (convergente simples/absolutamente ou divergente) da série $\sum_{n=1}^{+\infty} \left(\frac{n\alpha}{n+\alpha^2} \right)^n$ com $\alpha \in \mathbb{R}$.
- Considera a série de potências $S(x) = \sum_{n=0}^{+\infty} \frac{(-1)^n x^{2n+1}}{2n+1}$.
 - Determine a natureza da série para $x = -1$, $x = 1$ e $x = 2$.
 - Determine o domínio de convergência da série, indicando os pontos onde a convergência é simples e onde é absoluta.

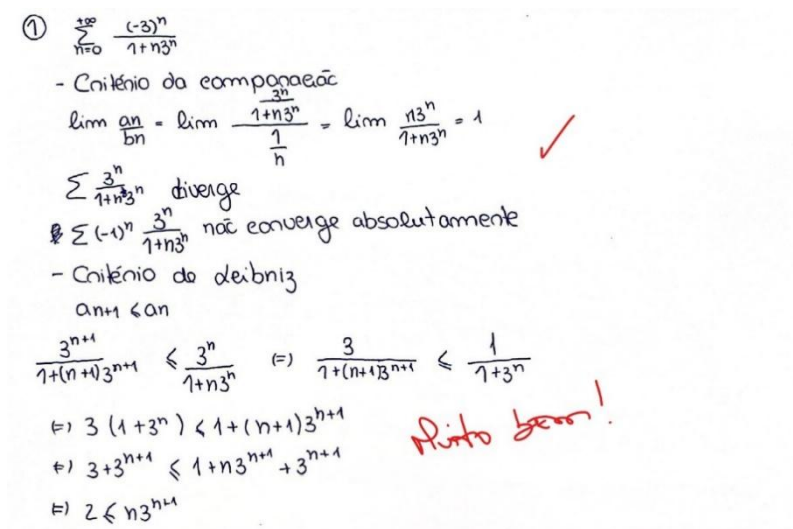
Resolução

Figure 1. Example of a task students had to submit after solving the exercises.

The page header contains the name of the course (*Cálculo I – B*), the assignment title (TPA means Task for Lecture) and the curricular topic (*Critérios da razão, da raiz e de Leibniz. Séries de Potências* - Ratio, Root, and Leibniz Criteria. Power Series).

The students had to fill the fields class TPB_ and group G_ and then the list of the students of the group that were present in that specific lecture. The group had to choose, in each task, who was going to be the manager/spokesperson (although they didn't respect a lot this mandate) and the writer/postman, i.e., the student who had to write and submit on Moodle the detailed answer. The others were collaborators. The only acceptable format for submission was PDF, and they had the warning "Before sending, check that the PDF file is of good quality!" Figure 2 shows an example of a submitted and corrected task.

The assignments were evaluated using the rubrics described in table 1, which the students knew from the beginning of the semester. Rubrics are a powerful tool in education that enhance clarity, fairness, and efficiency in the grading process, while also providing valuable feedback and promoting student self-assessment and reflection. "A rubric is a coherent set of criteria for student work that includes descriptions of the quality levels of performance according to the criteria" (Brookhart, 2013).



① $\sum_{n=0}^{+\infty} \frac{(-3)^n}{1+n3^n}$

- Critério da razão

$$\lim_{n \rightarrow \infty} \frac{a_n}{b_n} = \lim_{n \rightarrow \infty} \frac{\frac{3^n}{1+n3^n}}{\frac{1}{n}} = \lim_{n \rightarrow \infty} \frac{n3^n}{1+n3^n} = 1$$

$\sum \frac{3^n}{1+n3^n}$ diverge

$\sum (-1)^n \frac{3^n}{1+n3^n}$ não converge absolutamente

- Critério de Leibniz

$$a_{n+1} \leq a_n$$

$$\frac{3^{n+1}}{1+(n+1)3^{n+1}} \leq \frac{3^n}{1+n3^n} \Leftrightarrow \frac{3}{1+(n+1)3^{n+1}} \leq \frac{1}{1+n3^n}$$

$\Leftrightarrow 3(1+n3^n) \leq 1+(n+1)3^{n+1}$

$\Leftrightarrow 3+3^{n+1} \leq 1+n3^{n+1}+3^{n+1}$

$\Leftrightarrow 2 \leq n3^{n+1}$

Não tem!

Figure 2. Example of submitted task with (positive) feedback

Moodle allows group submissions; when the teacher grades the tasks all the elements of the group are notified, receive the same classification and can access the teacher's feedback, which can be provided in different formats: writing on the submitted task, as in Figure 2, or directly in Moodle boxes, as a general comment or in each rubric (see Figure 3).

Table 1: Assessment grid for tasks.

Criterion	Description
Understanding of Mathematical Concepts	4 - Demonstrates a deep and correct understanding of mathematical concepts, without errors.
	3 - Understands mathematical concepts well, with minor errors.
	2 - Understands the basic concepts but makes a few mistakes that do not seriously jeopardise the work.
	1 - Partially understands the concepts but makes several mistakes that affect the accuracy of the work.
	0 - Shows no understanding of mathematical concepts, with many errors.
Task organisation and presentation	4 - The work is very well organised, with a clear, logical and easy-to-follow presentation.
	3 - The work is well organised and the presentation is clear, with minor improvements possible.
	2 - The work is organised, but the presentation can be confusing in some parts.
	1 - The work is poorly organised and the presentation is difficult to follow.
	0 - The work is disorganised and the presentation is very confusing.
Justification and Argumentation	4 - Justifies all answers with logical and well-founded arguments.
	3 - Justifies most answers with solid arguments.
	2 - Justifies some answers, but with arguments that may be weak or incomplete.
	1 - Justifies few answers, with insufficient arguments.
	0 - Don't justify their answers or their arguments are invalid.
Use of mathematical language and representation	4 - Uses mathematical representations and language correctly and effectively.
	3 - Uses mathematical representations and language correctly, with minor flaws.
	2 - Uses some mathematical representations and/or language, but makes mistakes in some of them.
	1 - Uses few mathematical representations and/or language and makes many mistakes.
	0 - Does not use mathematical representations and/or language or uses them incorrectly.

Compreensão dos Conceitos Matemáticos	Não demonstra compreensão dos conceitos matemáticos, com muitos erros. 0 pontos	Compreende parcialmente os conceitos, comete vários erros que afetam a precisão do trabalho. 1 ponto	Compreende os conceitos básicos, mas comete alguns erros que não comprometem gravemente o trabalho. 2 pontos	Compreende bem os conceitos matemáticos, com erros menores. 3 pontos	Demonstra uma compreensão profunda e correta dos conceitos matemáticos, sem erros. 4 pontos	Tentar corrigir os erros
Organização e Apresentação da tarefa	O trabalho está desorganizado e a apresentação é muito confusa. 0 pontos	O trabalho está mal organizado e a apresentação é difícil de seguir. 1 ponto	O trabalho está organizado, mas a apresentação pode ser confusa em algumas partes. 2 pontos	O trabalho está bem organizado e a apresentação é clara, com pequenas melhorias possíveis. 3 pontos	O trabalho está muito bem organizado, com uma apresentação clara, lógica e fácil de seguir. 4 pontos	

Figure 3. Example of the evaluation grid

2.2 Peer assessment

As mentioned above, students were assigned to groups which were randomly changed every four working sessions, that is three times along the semester. After these four sessions each student evaluated themselves and their peers regarding their performance on the work developed together. Again, rubrics were used to normalize the assessment results.

Table 2. Rubrics for peer assessment.

Criterion	Description
Participation and involvement	4 - Always participates extremely active and enthusiastically in all tasks.
	3 - Participates actively and enthusiastically in solving tasks.
	2 - Participates in tasks regularly, but without much enthusiasm
	1 - Participates rarely in tasks and discussions and with little enthusiasm.
	0 - Does not participate in tasks or get involved in discussions.
Collaboration in solving tasks	4 - Always co-operates with colleagues, helping and encouraging them to solve all tasks.
	3 - Almost always co-operates with colleagues in solving tasks.
	2 - Occasionally co-operates with colleagues.
	1 - Co-operates rarely and only when asked.
	0 - Does not co-operate with colleagues in the group.
Respect for colleagues	4 - Always respects colleagues' opinions and shows empathy.
	3 - Often respects the opinions of colleagues.
	2 - Occasionally respects colleagues' opinions.

Responsibility	1 - Rarely respects colleagues' opinions.
	0 - Does not respect colleagues' opinions.
	4 - Always meets deadlines and fulfils assigned tasks.
	3 - Frequently meets deadlines and fulfils assigned tasks.
	2 - Occasionally fulfils the deadlines and tasks assigned to them.
	1 - Seldom fulfils the deadlines and tasks assigned to them.
	0 - Does not fulfil the deadlines and tasks assigned to them.

When answering peer assessment, the students were reminded of the following rule: "You must assess the performance of your classmates and your own performance. If you fail to do so, your grade in this component will be penalised by 30%. Be FAIR AND RESPONSIBLE in your assessment because this grade influences the final classification on the course". Nevertheless, they tended not to punish their peers, and if they did, the penalties were very soft.

	S1	S2	S3	S4	S5	S6	S7
S1	4/3/4/4	4/4/4/4	3/3/4/4	3/3/4/4	3/3/4/4	3/3/4/4	3/3/4/4
S2	3/3/4/4	4/4/4/4	4/4/4/4	2/3/4/4	2/3/4/4	0/1/4/4	2/3/4/4
S3	-	-	-	-	-	-	-
S4	4/4/4/4	4/4/4/4	4/4/4/4	2/2/4/4	4/4/4/4	1/1/4/4	4/4/4/4
S5	3/4/4/4	3/4/4/4	3/4/4/4	3/4/4/4	3/4/4/4	1/1/4/4	3/4/4/4
S6	4/4/4/4	3/3/4/4	4/4/4/4	3/2/4/3	3/2/4/3	1/2/4/3	3/3/4/3
S7	4/3/4/4	4/3/4/4	4/3/4/4	3/2/4/4	3/2/4/4	0/0/4/1	3/2/4/4

Figure 4: An example of a peer assessment evaluation of the four criteria, where student S3 did not answer

To assess their peers, students analyse the assessment criteria in more depth and, also, critically reflect on their own work. Receiving and giving feedback among peers promotes individual and social development, giving them the tools to critically analyse their work and that of others in the future, to communicate feedback in a constructive way, and to accept and incorporate the opinions of others into their work.

2.3 Assessment

A light version of continuous assessment was used in this Calculus course consisting of various elements collected throughout the semester, namely:

- Assignments completed during class throughout the semester – 12%;
- Peer assessment and self-assessment– 8%;
- Two online tests– 15% each;
- Written test in the last week of the term– 50%.

The online tests were conducted on Moodle using Multiple Choice Questions (MCQ).

MCQ can be graded quickly and objectively (Klufa, 2015), especially with automated systems. They allow for a wide range of topics to be tested within a single exam and scoring is less subjective compared to open-ended questions. With MCQ multiple versions of a test can be created easily, ensuring consistency in assessment, which is an asset when assessing hundreds of students. However, students can sometimes guess the correct answers, which can affect the reliability of the test, but (Klufa, 2015) states that the probability of scoring 50% or more in this kind of test is 0,011839.

Open ended questions (OED) complement MCQ: they can assess students' deep understanding and ability to articulate complex ideas; they encourage critical thinking and the ability to construct coherent arguments; students can express their knowledge in their own words, which can be more reflective of their understanding. Written exams allow for creative responses and problem-solving as OEQ aim to elicit detailed and comprehensive responses that provide insight into students' thought processes.

A written test was carried out in the last week of the term using OEQ, "giving the students the opportunity to provide different answers" (Bingölbali & Bingölbali, 2021).

In our opinion these four elements used in assessment are enough to classify students, despite the subjectivity inherent in an evaluation process.

2.4 Games used

Gamification in education has been shown to create a stimulating learning environment, encouraging active participation and collaboration among students. Some examples of games used in Education are presented in (Noda, Shiotsuki, & Nakao, 2019).

As referred to in (Radzi, Ying, Abidin, & Ahmad, 2020) "One of the specialties of board game is engagement and connectivity by enforcing active interaction between players during play session. Furthermore, board game enables players to foster a reflective environment for learning a certain knowledge context and enables player to creatively solve problem in the game world." Besides, board games introduce an element of fun and competition, which promotes motivation and can lead to deeper conceptual understanding and better retention of information.

The games used in our Calculus classes were "Guess who" played with the whole class and "The mysterious rule", about functions of one variable and their graphs; in the study of inverse trigonometric functions the game "Math Twins" was played and on antiderivatives we used "The antiderivatives box". These games were designed for group play, promoting teamwork and communication. This collaborative aspect can enhance learning by allowing students to discuss strategies, explain their reasoning, and learn from each other, turning classrooms in active learning spaces. The description of these games can be found in (Oliveira, 2024).

3 Discussion

3.1 Students' opinions

At the end of the semester, we asked students to complete an anonymous online survey ("Your opinion matters. Help us improve the course") with the purpose of evaluating the effectiveness of the teaching strategies implemented in our Calculus course.

The survey results show that students valued collaborative activities, such as group work and peer assessment, because they promoted a deeper understanding of the subjects and more active participation from everyone. One student wrote "In Group work (TPA), we can develop communication and teamwork skills and at the same time understand the subject better." Students also highlight the added benefit of staying up-to-date with the study of the taught topics and assisting in organizing their study.

The use of Vevox was particularly appreciated in the theoretical lectures, as it promoted real-time interaction and immediate feedback. One of the answers referred that "it created an effective learning environment".

In addition, the online tests and group work provided opportunities for continuous assessment, allowing students to track their progress throughout the semester. Despite some students not liking online tests due to

multiple-choice questions, overall, students appreciated the assessment method used because it included various components.

3.2 Analysis of the assessment results

In recent years, we have been teaching the Calculus course to first-year students, consistently implementing various strategies to engage students in the learning process. The undergraduate programs that include Calculus courses underwent changes in the 2023/24 academic year, which is when we began to deploy the methods discussed in this article.

By comparing the data for the last two years, we can observe a significant reduction in the number of students who did not participate in any form of assessment, decreasing from 12.03% to 6.85%. Achieving this reduction was one of our primary goals.

At the same time, pass rates increased both relative to the total number of students enrolled in the course and to the number of students assessed. In 2023/24, out of a total of 507 students, 53.85% passed, corresponding to 61.21% of those that were assessed. This year, 2024/25, 67.32% of the 511 students enrolled in the course passed, that is, 72.27% of the students who were assessed.

Another noteworthy aspect, supporting our belief that this methodology produces more lasting learning outcomes, is the increase in the number of students passing the resit exam. Indeed, considering only the total number of assessed students, given a similar pass rate for the regular exam (58.7% in 2023/24 and 59.53% in 2024/25), the pass rate for the resit exam raised from 2.51% to 12.74%.

In 2023/24, we implemented the methodology described in this article for the first time. There were still many aspects to refine, particularly in how tasks were submitted and assessed, in peer evaluations, and in making small adjustments to communication and resources provided to students. Additionally, the teaching team in 2024/25 was more cohesive and having a unified perspective on modern education. These factors may contribute to explain the improved results of 2024/25.

4 Conclusion

The implementation of innovative teaching strategies in the Calculus course for first-year students has shown promising results. By incorporating active learning techniques, peer assessment, and diverse evaluation methods, we have observed a significant improvement in student engagement and performance. The reduction in the number of students not participating in assessments and the increase in pass rates, both during regular and resit exam periods, highlight the effectiveness of these methodologies.

The challenges faced in the initial year of implementation, such as the quality of student submissions and the consistency of peer assessments, provided valuable insights for refining our approach. The improvements seen in the subsequent year, particularly in the robustness of the methods and the cohesiveness of the teaching team, further validate the positive impact of these strategies.

Overall, this study demonstrates that a combination of interactive learning tools, structured group work, and varied assessment techniques can significantly enhance the learning experience and outcomes for students in STEM disciplines. These findings offer valuable insights for educators seeking to adopt innovative approaches to foster deeper learning and improve student success.

A detailed analysis of the results of the survey and a discussion of the assessment results can be found in (Nolasco, Oliveira, & Vettori, to be published).

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Enhancing Inclusive Education in Higher Education: Best Practices for UDL Implementation

Inês Monteiro¹, Francisca Miranda¹, Diana Soares¹

¹ Universidade Católica Portuguesa, Faculty of Education and Psychology, Research Centre for Human Development, Porto, Portugal

Email: imfsantos@ucp.pt; fmiranda@ucp.pt; dsoares@ucp.pt

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Abstract

The increasing diversity of student profiles in Higher Education presents a valuable opportunity to enhance teaching and learning processes. However, for education to be truly inclusive, it requires an intentional approach. Creating an inclusive classroom environment is, therefore, a challenge for educators, who often face uncertainty about how to begin this process and what methodological approaches to adopt. Universal Design for Learning (UDL) offers a holistic framework focused on supporting the learning of all students and recognising diversity as the norm, encouraging, as well, the proactive identification of barriers within the curriculum, rather than attributing them to the students themselves. The goal of UDL is to create teaching and learning experiences that are accessible, inclusive, and flexible, regardless of individual student characteristics. Despite its potential, there are significant challenges to implementing UDL, including time and resource constraints, a lack of institutional support, and limited faculty awareness of this curriculum design model. Additionally, in Portugal, there is an absence of overarching guidelines or specific national legislation, leaving each Higher Education institution responsible for defining its own framework. This exploratory scoping review aims to analyse emerging trends and best practices in the implementation of Universal Design for Learning (UDL). Drawing on international case studies, it offers practical guidelines for designing inclusive lessons, emphasizing the importance of setting clear learning objectives and proactively addressing potential barriers to learning. The purpose of this summary is to support the effective transformation of teaching and assessment practices in Higher Education.

Keywords: Universal Design for Learning; Higher Education; Student-Centred Learning; Inclusive Education.

1 Introduction

Diversity emerges as an opportunity to enhance student learning. However, inclusion must be intentionally pursued to achieve this purpose. Conversely, the personalised adaptation of lessons, materials, and assessment elements can be perceived as laborious for educators. In addition, there is uncertainty regarding how to initiate this process and which methodological approaches to adopt (Sanger, 2020). The objective of this exploratory study is to investigate strategies planned and implemented in Higher Education at a curricular level, presenting them in a flexible way and offering a guiding proposal for planning inclusive lessons, informed by international examples and complementing existing guidelines (CAST, 2024).

Anticipating differences at the classroom level can promote greater inclusion and quality in education, benefiting all students (Sanger, 2020). In this context, the Universal Design for Learning (UDL) framework will be addressed from an inclusion-facilitating perspective, referring to the planning and curricular organisation around universal measures, with accessible, flexible, and effective actions (King-Sears et al., 2023). According to the [guidelines](#) proposed by CAST (2024), the promotion of the following principles are suggested for a student-centred learning: (1) Engagement: multiple means of engagement—the ‘Why’ of learning; (2) Representation: multiple means of representation—the ‘What’ of learning; and (3) Action and Expression: multiple means of action and expression—the ‘How’ of learning.

2 Methodology

2.1 Objective and research questions

The decision to undertake a scoping review was adopted as the most suitable method for mapping the existing literature on the implementation of the Universal Design for Learning framework in Higher Education. An exploratory study, focusing on trend analysis, was conducted, examining publications from the last two years. This approach was deemed appropriate for synthesising available knowledge, identifying key concepts, and exposing gaps in the literature. These objectives are materialised in the following Research Question (RQ):

RQ1: How is Universal Design for Learning (UDL) planned, implemented, and evaluated in Higher Education Institutions?

2.2 Eligibility criteria

Once the research question was established, the eligibility criteria for the scoping review were defined by the research team. The eligibility criteria resulted in the inclusion of: 1) documents indexed in Scopus or WoS databases; 2) documents with keywords found in the article title, abstract, or keywords in the case of Scopus, or in the abstract in the case of WoS; 3) documents written in English, Portuguese, or Spanish; 4) documents published in the last two years; 5) documents from all subject areas; 6) open Access; and 7) only articles were considered. The first set of exclusion criteria included: 1) studies not conducted in Higher Education; 2) studies focused on specific topics unrelated to the implementation of UDL in Higher Education; 3) theoretical studies; 4) editorials; 5) literature reviews; 6) articles with restricted access; and the final criterion: 7) studies focused on specific topics unrelated to education.

2.3 Identification of databases and search terms

The studies were identified through the Scopus and Web of Science (WoS) databases. Despite recognising potential limitations, such as the exclusion of other valuable articles, the choice of these databases is justified as they are considered the most comprehensive data repositories for various purposes (Pranckutė, 2021). In terms of the methodological approach, the initial step involved defining keywords and constructing the search query. The search terms used were as follows: ("Higher education" OR universit* OR college OR "tertiary education" OR "post-secondary education") AND ("universal design for learning" OR "UDL" OR "universal design" OR "UD").

2.4 Selection of Studies

The subsequent steps in the methodology involved the organisation and categorisation of the data to address the central research question, followed by the comparison and analysis of the collected data. In the initial phase of research, a total of 149 publications were identified (74 in WoS; 75 in Scopus). After the removal of duplicates, 115 articles remained. Subsequently, 79 articles were excluded for not being related to the study's theme and objectives, for UDL implementation being applied in extracurricular activities rather than in curricular areas, the article not being published in a journal related to Educational Sciences or for being review articles. Consequently, in accordance with the inclusion and exclusion criteria, 36 articles were thoroughly analysed. Following a full-text screening, 24 publications were excluded for not presenting or describing specific UDL strategies or for restricted access, resulting in a total of 12 articles. This selection methodology was based on PRISMA – Preferred Reporting Items for Systematic Reviews and Meta-Analysis (Moher et al., 2009).

3 Data analysis and Discussion

Following the various stages of screening and selection, a total of 12 articles were included in the scoping review. These articles were all published in 2024 ($n = 12$) and none in early 2025 ($n = 0$), reflecting the exploratory nature of the study and its focus on capturing the most recent research developments. Based on the geographical data reported in the studies, five were conducted in the United States, two in the United Kingdom and one each in Australia, Chile, China, Spain and Turkey. This distribution demonstrates a wide international representation: Asia, America, Europe and Oceania. However, it also highlights the absence of national contributions and representativity (Portugal). The target population of these studies comprises general students in eight articles. Two of these articles also include neurodivergent students and students with disabilities in their samples. Additionally, one article each represents international students, students with disabilities, and working-class students. The selected articles were subjected to content analysis to address the research question: *How is Universal Design for Learning (UDL) planned, implemented, and evaluated in Higher Education Institutions?* Based on the analysis, the results are organised into the following thematic categories: (1) Curriculum Planning and Design, (2) UDL Implementation Strategies, and (3) Evaluation of UDL Implementation.

3.1 Curriculum Planning and Design

One of the key aspects in the implementation of UDL is its integration at the level of curriculum design, including the definition of learning objectives, the specification of intended competencies, and the methods of assessment (Knarlag, 2016). In the present scoping review, five of the twelve studies analysed propose a curriculum design or redesign based on UDL principles (Manly, 2024; Montgomery et al., 2024; Rao et al., 2024; Redstone & Luo, 2024; Seymour, 2024). Of these, four are focused on online learning environments, while one pertains to face-to-face instruction within a work-integrated learning context. Among the studies reviewed, four incorporated all three UDL principles—Engagement, Representation, and Action and Expression—into their curricular restructuring, whereas one (Seymour, 2024) addressed only the principle of Engagement, summarised in Table 1.

Table 1. Analysis of Studies in Curriculum Planning and Design

Referenced Studies	Modality	Multiple Means of Engagement	Multiple Means of Representation	Multiple Means of Action and Expression
Manly (2024)	Online	- Option to choose the start date of the course unit (7.1) - Completion of online quizzes for progressive access to content (8.2) - Opportunities for discussion and feedback through an online forum (8.2; 8.3; 8.4; 8.5; 9.2)	-Access to diversified resources (1.2) -Access to technology in the classroom (1.1)	-Discussion group with student-suggested topics (5.3) -Diversified assessment methods (e.g., video creation; audio; text) (5.2)
Montgomery et al. (2024)	Online	-Problem-Based Learning (8.3) - Student autonomy in selecting problem questions (7.1) - Frequency of theoretical, laboratory, and workshop classes (7.2.)	-Synchronous and asynchronous classes (1.2.)	-Choice of structure and format for the final conference presentation (5.1; 5.2)
Rao et al. (2024)	In person (work-integrated learning)	-Establishment of equity and inclusion values (7.4) -Definition of learning objectives, assessment methods, and activities to implement (8.1) -Post-internship reflection, conducted in multiple formats (9.3) -Community of Practice (CoP) among teachers (8.3)	-Raising teacher awareness of cultural and diversity issues e (1.3)	-Definition of inclusive feedback and assessment moments (4.1; 5.2; 5.3) -Communication with students during internships (e.g., periodic check-ins) (6.4)
Redstone & Luo (2024)	Online	Course syllabus: -Instructor information (7.2) -Clarification of assessments in relation to learning objective (8.1)	-Supplementing texts with multimedia resources, consolidated on a single page (1.1) -Creation of concept maps (1.2) -Description of alternative materials to texts (2.1)	-Discussion Board (5.3) -To-Do List for clarifying objectives (6.1; 6.3) -Course scheduling and online definition of assignment due dates (6.2)
Seymour (2024)	Online	-Asynchronous weekly tasks (e.g., quizzes, podcasts, films, recordings; surveys, case studies) (7.3; 8.2)		

		-Instructor availability to contact students (e.g., reinforcing discussion topics and aligning with learning objectives) (8.1; 8.5) -Signposting (7.1; 7.2) -Addition of accompanying images to communicate content (8.1; 8.5) -Delineation of topics (8.2) -Structured online group activities (e.g. ethical dilemma) (8.3; 8.4)		

3.2 UDL Implementation Strategies

This category outlines the implementation of teaching activities and strategies in which UDL principles were applied. In this scoping review, eight out of the 12 studies analysed report the implementation of strategies and activities within classroom or equivalent settings (Adler & Kletenik, 2024; Durgungoz & Durgungoz, 2024; Evmenova et al., 2024; Gill et al., 2024; Navarro et al., 2024; Qu & Cross, 2024; Ramos & Wilson-Kennedy, 2024; Seymour, 2024). Among the studies presented, five applied the full range of UDL principles, one applied two (Engagement and Representation), and two applied only one principle (Engagement). The characteristics of the studies, along with selected replicable strategies and their corresponding UDL checkpoints, are summarised in Table 2.

Table 2. Analysis of Studies in UDL Implementation Strategies

Referenced Studies	Multiple Means of Engagement	Multiple Means of Representation	Multiple Means of Action and Expression
Adler & Kletenik, 2024	-Gamification (competition; challenge) (7.3) -Self-reflection between rounds, based on the scores obtained (7; 8; 9)		
Durgungoz & Durgungoz, 2024	-Active Learning (gamification; flipped learning; group discussions; scenario-based learning) (7; 8; 9) -Interactive feedback to clarify objectives, monitor progress, and avoid distractions (e.g., gamified quizzes) (7.2; 7.3; 8.5) -Lectures related with real-world examples (7.2) -Outline lecture objectives and summarised key points at the end (8.1)	-Integration of technological tools (e.g., Canva; Padlet) (1.2; 2.5) -Prior access to diverse instructional materials (e.g., videos; podcasts) (1.2) -Begin lecturing with a brief review of previous material (3.1) -Provide lecture notes in advance (1.1) -Present keypoints visually (1.1)	-Multiple media for communication (e.g. lectures; demonstration videos) (5.1)
Evmenova et al., 2024	-Offer choices in assignments, assessments (e.g. text; photo; quizz) (7.1) -Feedback via formal/informal means (7.3) -Simulation, hands-on activities (7.2) -Clear goals and timelines (8.1) -Step-by-step guides (8.2) -CoP (8.3) -Peer assessments and feedback (8.4) -Gender-neutral language (9.1)	-Offer print/digital versions of books/readings (1.1) -Make auditory content visual (1.2) -Offer color inversion (1.3) -Define key terms (2.1) -Explain module organisation (2.2) -Make some readings optional (2.3) -Provide links to translators (2.4) -Multiple tools to offer content (video; podcasts) (2.5) -Break lectures for discussion (2.5)	-Vary participation in discussions and submission of assignments (4.1) -Use dictation and voice typing tools (4.2) -Multiple forms of interaction (e.g. synchronous; asynchronous; individual) (5.1) -Allow to express understanding in words, diagrams or other (5.2) -Allow drafts for feedback (5.3) -Share weekly objectives and individual goals (6.1)
Gill et al., 2024	-Active Learning: Use of gamified challenges (e.g., discussions, decision-making, and collaborative work; active participation) (7; 8; 9) -Freedom in workgroup role selection (7.1)	-Vocabulary clarification (2.1) -Use of videos, 3D models, and physical puzzles to provide access to additional materials for lectures and repeated viewing of content (1; 3)	-Feedback sessions (6.4) -Peer-to-peer discussion (4.1; 6.5) -Freedom in task selection (5.1; 5.3) -Competitive Speed Challenge (5.2; 6.2) -Microlearning content (5.2) -Completing Physical Puzzle (4)
Navarro et al., 2024	-Creation of accessible videos for students, aimed at peers with cognitive, sensory, or linguistic issues (7; 8; 9) -Teacher supervision and collaboration in video creation (7.3) -Multidisciplinary teaching staff (7.2) -Collaborative work and shared responsibility (8.3)	-Multiple means of accessing content, shared through the video script (e.g., text; images; elimination of irrelevant information) (1.2) -Videos: Visual illustrations accompanied by voice (highlighting important information) (1.1; 2.5)	
Qu & Cross, 2024	-Group work with UDL principles: Definition and distribution of specific tasks within the group (e.g., poster creation; leading a debate) (7.1; 8.3)	-Provision of materials based on text, video (1.2) -Integration of student projects into teaching materials (1.3)	-Online discussion forum (5.2; 5.3) -Feedback, reflection, and diverse assessment (e.g., weekly poster creation and presentation) (5.3; 6.4) -Option for summative or formative assessment method (4.1)
Ramos & Wilson-Kennedy, 2024	-Using AI: -Creation of culturally inclusive learning scenarios (7.4; 8.4; 9.1)	-Using AI: -Mobilization of culturally relevant examples (1.3)	-Using AI: -Inclusive learning environments: Access to content via mobile phones by rural

	-Translation tools (8.2) -Problematization of real-world scenarios (7.2) -Clarification of complex concepts (8.2)	-Personalization of learning processes (1.3)	populations or those with deficient infrastructure (4.2; 6.5) -Diversification of assessment methods (4.1)
Seymour, 2024	-Weekly preparation of documents and tasks (8.2) -Weekly communication via email (8.2; 8.5) -Group discussions (8.3) -Negotiation of curriculum content (7.1) -Online recorded instructions (8.2)		

Through the curricular restructuring and lesson planning described, it becomes clear that only 33% of the studies analysed implemented the full range of UDL principles in the curriculum and 42% addressed the second premise. This partial adoption of UDL principles may be attributed to the fact that only one of the studies mentioned institutional support for teaching staff by academic personnel. Faculty training is regarded as one of the most crucial factors for the development of intentional and effective practices, as highlighted in the systematic review conducted by Seok et al. (2018). Such support can be seen as a pioneering institutional measure, particularly in raising awareness of UDL—an area that has yet to become a widespread practice within the Portuguese higher education context also (Maia & Santos, 2024). Nevertheless, it is important to emphasise that the majority of the practices described align with principles that enhance the effective implementation of UDL. These include the use of practical examples during classes, hands-on activities reflecting active learning strategies (in multiple means of engagement principle), flexible assessment opportunities, and the provision of ongoing feedback throughout the course (Seok et al., 2018).

3.3 Evaluation of UDL Implementation

This category outlines how activities or projects that operationalise UDL principles were evaluated, particularly from a methodological standpoint. In parallel, the main findings are also briefly presented in Table 3. In this review, 10 out of the 12 studies analysed reported on the evaluation of the implementation of strategies based on UDL principles (Adler & Kletenik, 2024; Durgungoz & Durgungoz, 2024; Evmenova et al., 2024; Gill et al., 2024; Manly, 2024; Montgomery et al., 2024; Navarro et al., 2024; Redstone & Luo, 2024; Qu & Cross, 2024; Seymour, 2024). Of these, seven employed a mixed-methods approach, two adopted quantitative methodologies, and one only utilised a qualitative methodology.

Table 3. Analysis of Studies in Evaluation of UDL Implementation Strategies

Referenced Studies	Variables & Methodology	Main Findings
Adler & Kletenik, 2024	-Mixed-Method: satisfaction with the initiative; performance; empathy and attitudes towards people with disabilities	-Accessibility games educated students about challenges and increased consideration for users with disabilities -Integrating accessibility-focused games in classrooms enhances student learning outcomes -Games improved students' attitudes towards people with disabilities and understanding of barriers, with a large effect size for the latter
Durgungoz & Durgungoz, 2024	-Mixed-Method: students' engagement; students' perspective about the strategies implemented	-UDL strategies significantly improved cognitive and emotional engagement for ND and NT students, with ND students showing a more pronounced increase in emotional engagement. -ND students preferred anonymous, technology-driven interactions and practical tasks over group discussions, which they found overwhelming
Evmenova et al., 2024	-Mixed-Method: student feedback; course satisfaction (pedagogical inquiries)	-Improvement in academic outcomes compared to traditional courses
Gill et al., 2024	-Mixed-Method: interest/enjoyment, perceived competence, and perceived choice (Intrinsic Motivation Inventory); Hedonic and pragmatic qualities (user-experience questionnaire); Students' preference (interviews; self-reports)	-The AR DfMA game received high ratings for its pragmatic and hedonic qualities -The game boosted intrinsic motivation and enjoyment of learning DfMA concepts -Students appreciated the hands-on, collaborative, and active learning aspects, enhancing their learning experience and motivation
Manly, 2024	-Quantitative: causal effects of using multiple modalities in learning (LMS platform data)	-Multiple modalities (text, video, audio, interactive) had a positive, medium-large, and meaningful effect on student learning gains in an adaptive learning system -Results support UDL's principle of multiple means of representation and suggest incorporating different modalities into courses
Montgomery et al., 2024	-Mixed-Method: knowledge acquisition (students' perception; Likert scale); students' confidence	-Statistically significant changes from the beginning to the end of the course, suggesting that participants reported a significant impact on their progress -UDL-inspired adaptations improved student confidence in applying the scientific method and their perception of problem-solving abilities

Navarro et al., 2024	-Quantitative: collaborative work; interest in the subject; academic results	-Student-created video capsules improved academic performance in laboratory practicals -Enhanced collaborative work and interest in the subject, but no apparent influence on final exam results -The activity developed instrumental (e.g. procurar e gerir informação), interpersonal (e.g. relação com pares), and systemic competencies (e.g. aplicação de conhecimentos)
Redstone & Luo, 2024	-Mixed-Method: academic success; engagement; self-efficacy; perceived benefits and challenges by the teacher	-Significant effects on student self-efficacy and engagement, but no significant impact on academic results -The instructor was pleased with the UDL-redesigned course and plans to use it again
Qu & Cross, 2024	-Qualitative: most valued key factors (focus group)	-Students valued technologies, face-to-face support, motivating activities, and cultural/social diversity awareness, aligning with UDL principles
Seymour, 2024	-Mixed-Method: engagement; subject interest (focus group; survey)	-Course restructuring based on the Engagement principle improved student interest and involvement

Regarding the effectiveness of UDL implementation, although further research at the Higher Education level is warranted, existing evidence indicates a moderate impact on academic success. Notably, disparities have been observed between students who benefit from the model and those who do not, with the former advantaged through the reduction of barriers at both the curriculum and instructional levels (King-Sears, 2023). As confirmed by the previously cited meta-analysis, only 33% of the studies included in the review demonstrated intervention effects; however, these were positive in terms of academic achievement (Navarro et al., 2024; Manly, 2024), as well as in improving students' confidence and self-efficacy (Montgomery et al., 2024). Moreover, increased levels of engagement were reported, particularly among neurodivergent students when compared to their neurotypical peers (Durgungoz & Durgungoz, 2024).

4 Conclusion

The contribution of this exploratory study lies in the summarisation and organisation of the most recent practical examples from the literature, which serve as facilitator for the effective implementation of UDL. However, its efficacy is contingent upon a comprehensive institutional approach (Moriarty & Scarffe, 2019 in Hills et al., 2022). Indeed, without top-down initiatives (e.g. the recruitment of staff capable of providing implementation support; formalising UDL as an organisational practice; inclusion of UDL in internal policies) that ensure access to tools and infrastructure, UDL implementation is likely to be inconsistent, thereby perpetuating barriers to learning, particularly among disadvantaged groups and students with disabilities (Hills et al., 2022). In fact, only one of the reviewed studies referenced structured institutional support, underscoring a significant gap in faculty development. As emphasised by Seok et al. (2018), continuous professional development is essential for fostering intentional and effective UDL practices: promoting communities of practice, integrating UDL into staff training, and providing access to diverse pedagogical resources can catalyse a broader cultural shift within institutions. Furthermore, a cross-analysis of the strategies presented reveals a strong emphasis on active learning, with widespread use of gamification, collaborative tasks, and flexible assessment formats. These approaches, aligned with UDL principles, reflect a shared commitment to student engagement, autonomy, and accessibility, yet their full potential will only be realised through sustained institutional and pedagogical investment. This study presents limitations inherent to its exploratory nature and the limited number of examples covered. Additionally, future research must investigate the effects of UDL implementations also based on different subject areas.

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Transforming Education: The Impact of Active Learning in Engineering Courses

Raquel Faria¹, Teresa Melo Fragoso^{1,2}, Nuno Cid Martins¹

¹ Polytechnic University of Coimbra, Rua da Misericórdia, Lagar dos Cortiços, S. Martinho do Bispo, 3045-093 Coimbra, Portugal

² Research Group on Sustainability Cities and Urban Intelligence (SUScita), Polytechnic Institute of Coimbra, Rua Pedro Nunes - Quinta da Nora, 3030-199 Coimbra, Portugal

Email: rfaria@isec.pt, terefrag@isec.pt, ncmartins@isec.pt

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Abstract

In education area, active learning has proven to enhance academic achievement, including in some of the more difficult subjects such as engineering. Students learn better when the methodologies employed are centred around them and not only remember information more easily but also apply it more effectively during exams and in real life. This paper documents the changes made to the teaching and assessment methodology over a five-year period for an Applied Mechanics course offered to first-year Electromechanical Engineering students from the academic year 2019/2020 to 2023/2024. The course started with lectures and a single final exam but has since undergone transformation towards an active learning paradigm. Early changes included segmenting the final exam into multiple smaller tests that encouraged class participation. Later, the course was restructured to a flipped learning model with mini-tests and ongoing assignments to foster student participation and understanding. The data shows a remarkable improvement in performance; pass rates have increased from 27% to about 85%, although dropout rates tended to fluctuate over the years. The key takeaway is that a shift to active learning, alongside increased variety in assessments and interactive teaching, markedly improves student engagement and reduces attrition rate significantly. This showcases the opportunity students must learn effectively when guided seamlessly through the implementation of active learning techniques. Analysis has validated the move from a teacher-dominated learning approach to a student-centred approach prioritized in this study, which integrated continuous evaluation with tailored assessments, was most effective for achieving learning outcomes. Additional recommendations include using feedback for engagement refinement, designing specific participation strategies, and using advanced technological tools to stimulate active learning of the aims of the course. This demonstrates the rich opportunities for the application of sophisticated innovations in engineering education that can shape self-directed learners across all educational levels. In conclusion, the study underscores the propulsive effect of activity-based teaching methods on learning in engineering education while providing guidance for future enhancements to teaching frameworks.

Keywords Teaching Innovation; Active Learning; Engineering Education.

1 Introduction

There is a considerable change taking place in higher education which is primarily caused by the changes in the demand and expectation of learners (Brandt et al., 2025; Sunarsi et al., 2025). The “soak-and-sponge” approach where lectures are given, and students passively listen has been greatly shattered. Students are not soaking up information as lectures are becoming increasingly redundant regarding modern-day career requirements (World Economic Forum, 2025). It is no secret that students at this moment find it difficult to engage with the material because of the rigid classroom setup. This disinterest, combined with focusing on recitation instead of cultivating reasoning, stifles students’ ability to sharpen their problem-solving and analytical abilities. In attempts to address these problems, (Cole, 2024) and (Felder & Brent, 2009) highlight the emergence of active learning strategies that more successfully achieve learner needs. PBL, project-based learning, as well as flipped learning foster collaboration and hands-on experiences where the learner is more actively engaged with the material. (Santos et al., 2024) and (Freeman et al., 2014) discuss these approaches. Consistent with these findings are (Stieha, 2024) and (Chang et al., 2022) which observe an increase, alongside enhanced academic performance, in creativity, teamwork, and motivation due to adoption of these methods.

(Yildirim, 2024) notes the strong impact of the STEM (Science, Technology, Engineering, and Mathematics) education flipped classroom model has had in fostering independent learning, peer to peer evaluation, and immediate feedback interactions.

Flipped learning has become more widespread due to its promise to transform the classroom experience. Instead of participating in lectures during class, students interact with the content's basics using videos and other learning materials so that class time can be devoted to discussion, problem-solving, hands-on work, and all other forms of interactive learning (Doung-In, 2017; Talbert & Bergmann, 2017). Students employ different learning styles and enhance their understanding through collaborative learning (Bishop & Verleger, 2013). This change allows students to interact with the material on their own while working through structured group activities (Bishop & Verleger, 2013). Test results of case studies from the STEM disciplines have proved that these methods enhance retention and problem-solving abilities. On the other hand, there are many barriers to its implementation—many educators trained with conventional methods tend to resist change, and it is commonly known that educational institutions do not have sufficient funding to offer the suitable support and training (Lau et al., 2024; Shi et al., 2023; Lima et al., 2024).

Assessing learners in the context of active learning requires evaluation from a different angle. Modern evaluation methods focus on more than just exams and include project-based evaluations, peer reviews, and cumulative feedback (Patiño et al., 2023). Formative assessment is an assessment technique that spreads evaluation throughout the semester, which is the opposite of concentrating it in high-stakes examinations. This approach helps alleviate stress and encourages gradual improvement during the semester (Cardozo et al., 2023). These evaluation techniques encourage analysis, synthesis, real-world application — key components of Bloom's Taxonomy —, and other aspects of learning which aids students to engage with the material at a deeper and more significant level (Kusmawan, 2025; Bloom, 1956).

In the world of STEM education, where being adaptable and innovative is key, active learning aligns perfectly with what industries are looking for (Theobald et al., 2020; Freeman et al., 2014). As companies increasingly seek out professionals who excel in problem-solving and teamwork, Higher Education Institutions (HEIs) must embrace teaching methods that equip students to meet these expectations (Nguyen et al., 2021; Jaroenphasemmesuk et al., 2023). However, challenges like inflexible curricula and scarce resources often hinder the implementation of these strategies. For meaningful change to take place, educators, policymakers, and institutional leaders need to collaborate in fostering an environment that encourages dynamic teaching practices and supports faculty development (Lau et al., 2024).

This study dives into the implementation of active learning strategies, particularly flipped learning, in an Applied Mechanics course — a crucial component of the Electromechanical Engineering Bachelor's degree program — over five academic years, from 2019/2020 to 2023/2024. At first, students encountered significant hurdles in grasping the course material, which led to a series of instructional tweaks, including flipped instruction, collaborative problem-solving tasks, and diverse assessment methods like mini-tests and peer discussions. By examining student performance data throughout this period, the study sheds light on how these adjustments influenced learning outcomes. The results add to the ongoing conversation about enhancing STEM education through innovative teaching approaches, highlighting the need for more interactive and student-centred learning environments. The paper is structured as follows: Section 2 outlines the course framework, detailing its objectives, student demographics, and the evolution of teaching strategies. Section 3 provides an analysis of student performance trends and approval rates, situating the findings within the context of existing literature. Finally, Section 4 concludes with recommendations for integrating active learning in STEM education and suggests potential paths for future research and teaching enhancements.

2 Methodology

To kick things off for this study, it's important to provide a snapshot of the Applied Mechanics course, who it's aimed at, and how teaching methods and assessment strategies have evolved over the last five academic years. This context sheds light on the main elements of the course content, its goals, and the tweaks made to boost student engagement and performance. It also gives us a glimpse into the changes that have been put in place to meet students' needs and adapt to the ever-evolving educational landscape.

2.1 Course description and target group

The Applied Mechanics course, which takes place in the 2nd semester of the 1st year for students pursuing a bachelor's degree in Electromechanical Engineering (EEB), is worth 5 ECTS (European Credit Transfer and Accumulation System) and includes 4 hours of contact each week. This is split into 2 hours of theoretical instruction and 2 hours of theoretical-practical work. The main goal of this course is to equip students with essential concepts and tools in physics as they relate to Mechanical Engineering, particularly focusing on Statics. Since this is a foundational course, it's crucial for students to grasp the material well, as it lays the groundwork for other subjects in the curriculum, like Strength of Materials and Machine Elements.

At the start, the teaching approach involved traditional lectures for the theoretical parts and problem-solving sessions for the practical components. Students were assessed through a final exam, which had a total score of 20 points, with the theoretical section making up 30% and the practical section 70%. Initially, the academic performance of students was concerning, with only a 27% success rate (the percentage of students who passed out of those evaluated), while about 33% of students did not participate in the assessment (the percentage of enrolled students who were not evaluated).

The focus of this study is on 1st-year EEB students, whose ages range from 18 to 50 across various academic years, but the average age tends to be around 22. When it comes to admission criteria for this group, during the period in question, most students entered through the General Access Regime (GAR). However, a notable number also came through professional pathways or as holders of Higher Professional Technical Courses (CTeSP). For example, in the 2023/2024 academic year, 69% of students were admitted via GAR, while 24% came through CTeSP or other professional pathways, with 8% each from special regimes. Unfortunately, the number of students enrolled in the course has been on the decline, with only 30 students registered for the 2023/2024 academic year. This drop is largely attributed to the increasing academic success rates.

2.2 Evolution of teaching methods and assessment strategies

This study takes a closer look at how teaching methods and assessment strategies have evolved over five academic years, spanning from 2019/2020 to 2023/2024. It highlights some significant changes and adaptations in how educators approach teaching and evaluation.

In the 2019/2020 academic year, the focus was mainly on traditional lectures and theoretical-practical sessions that emphasized problem-solving. The assessment strategy was straightforward, relying heavily on a final exam, where the theoretical part made up 30% and the practical part accounted for 70% of the final grade. Moving into 2020/2021, things started to shift with the introduction of active participation in the classroom. This meant that students were encouraged to ask questions related to the lesson content, which helped them engage more deeply with what they were learning. The assessment strategy was tweaked to include these class questions, which counted for 10% of the final grade, while the final exam still held its previous weight, making up 90% of the total. In 2021/2022, the focus on active participation and class questions continued. The assessment strategy stayed mostly the same, but two tests were introduced to replace the final exam, allowing for a more continuous evaluation of student performance. The 2022/2023 academic year brought a notable

change with the introduction of flipped learning in selected classes. This approach aimed to boost student engagement and promote self-directed learning. The assessment strategy became even more varied, with class questions still at 10%, three flipped learning tasks contributing 15%, and four mini-tests replacing the previous two tests, now making up 75% of the total grade. Finally, in the 2023/2024 academic year, the focus was on consolidating the changes made in the previous years, so no major adjustments were made to the teaching methods and assessment strategies. This stability suggests that the adaptations from earlier years were effective and well-received by both students and educators.

This change shows a move towards teaching methods that are more interactive and focused on students, backed by a varied assessment approach that highlights ongoing evaluation and active participation. Figure 1 shows how teaching methods and assessment strategies have evolved over the five academic years.

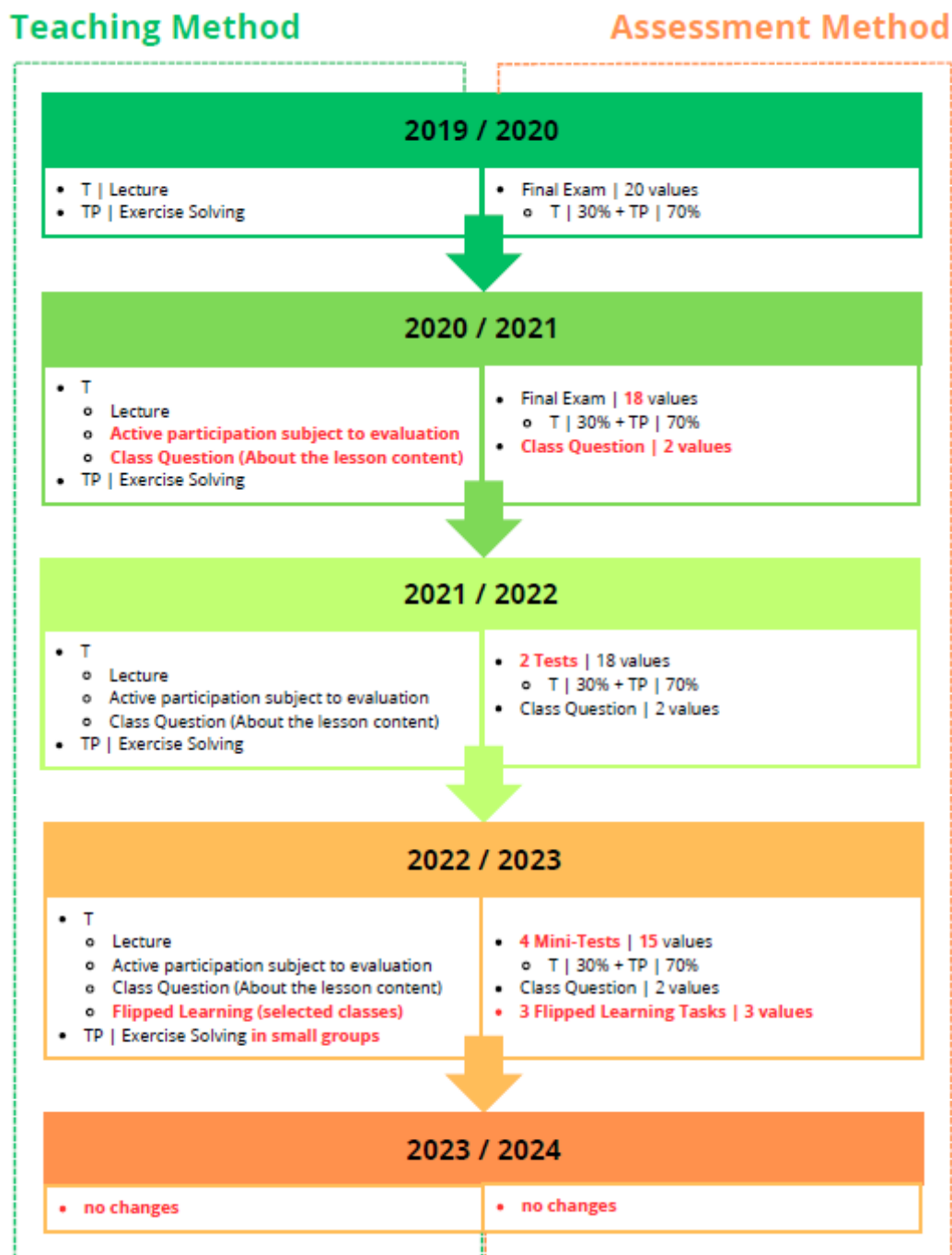


Figure 1. Evolution of teaching methods and assessment strategies

2.3 Flipped learning tasks

As mentioned earlier, we carried out flipped learning tasks in carefully chosen classes, targeting content that students often find tough to grasp. This approach hands some of the learning responsibility over to the students, giving them the chance to dive into topics at their own speed before jumping into classroom discussions and activities. Figure 1 shows how these flipped learning tasks were part of the assessment, encouraging students to get involved and make meaningful contributions to their learning journey.

We designed three flipped learning tasks, each one ramping up in difficulty, keeping in mind that most students, if not all, were new to active teaching methods, especially flipped learning. Every task included a phase for peer discussion. We believed that, in addition to learning at their own pace, fostering peer interaction through group discussions, collaborative learning, and structured teamwork helps build a sense of community and shared responsibility, which is key to student success. We also made sure to write the task instructions clearly and directly, providing all the necessary details about the activity. So, for each task, we included not just the description but also the topic, sub-topic, context, learning objectives, the nature of the task (whether it was collaborative, individual, or group), the execution period, submission deadline, required software/materials, how to deliver the work, the peer discussion platform, and the assessment rubrics.

The structure and implementation of these flipped learning tasks align well with educational frameworks such as Bloom's taxonomy and Kolb's learning styles (Bloom, 1956; Kolb, 1984). Students' progress through cognitive levels, from understanding foundational material to creating original outputs, reflecting Bloom's emphasis on higher-order thinking skills. Simultaneously, the design follows Kolb's experiential learning cycle, integrating concrete experience, reflective observation, abstract conceptualization, and active experimentation. This theoretical alignment reinforces the pedagogical robustness of the course's transformation.

The descriptions for the three proposed activities were pretty much the same, except for Task 3, which had an additional phase. It's important to mention that, besides students being able to access the instructions on the institution's management platform, all tasks were also discussed in the classroom, where any questions from the students were addressed.

2.3.1 Phase 1 – Reading

In this stage, we point out the reference materials that students should investigate, like specific sub-chapters from the recommended textbook, YouTube videos, and scholarly articles. Of course, students are welcome to explore other resources as well, and we make sure to let them know this. However, since this is a first-year course, it's crucial to guide them towards trustworthy sources, as a simple internet search doesn't always lead to reliable information.

2.3.2 Phase 2 – Project

After diving into the materials from Phase 1, students were tasked with a fun little project to put their newfound knowledge to the test. Each student had to come up with an original project for all the assignments. For Task 1, which was meant to be the easiest in terms of content and effort, they were asked to create a unique meme related to the sub-topic they were studying. Surprisingly, this turned out to be the toughest challenge for them. Since they were new to the flipped learning approach, the request to think "outside the box" made it hard for them to kick off their projects. However, after a bit more clarification on what was expected, some interesting results started to emerge. This experience also helped us refine how we present tasks in the following years, making things much clearer for everyone involved.

2.3.3 Phase 3 – Discussion Forum

During this phase, we used platforms like Moodle, Jamboard, and Padlet to encourage peer discussions. Students were required to share their completed work before the submission deadline, allowing them to receive feedback from both their classmates and the instructor. This way, they could make any necessary improvements before the final deadline. The collaborative aspect of this phase was a hit with the students, who engaged actively and showed great support for one another. Moreover, as part of ongoing assessment, the instructor offered hints and posed questions to help students enhance their work.

As previously mentioned, the final task included an additional step between Phase 2 and Phase 3, which involved creating an infographic that was then discussed with peers on the Padlet platform.

3 Results and Discussion

As shown in Figure 2, a longitudinal look at the indicators highlights some interesting trends over the five academic years from 2019/2020 to 2023/2024.

When we examine the percentage of student approval among those evaluated, we see that the lowest rate was in 2019/2020, sitting at about 27%. However, things started to improve in the following years, climbing to 56% in 2020/2021 and then reaching 74% in 2021/2022. This boost can be attributed to the introduction of active participation assessments and the shift from a single final exam to two assessment tests. By the next two years (2022/2023 and 2023/2024), the approval rate levelled off at around 85%, thanks to more significant changes in teaching and assessment methods, like flipped learning and a more varied evaluation approach that included mini-tests and assignments.

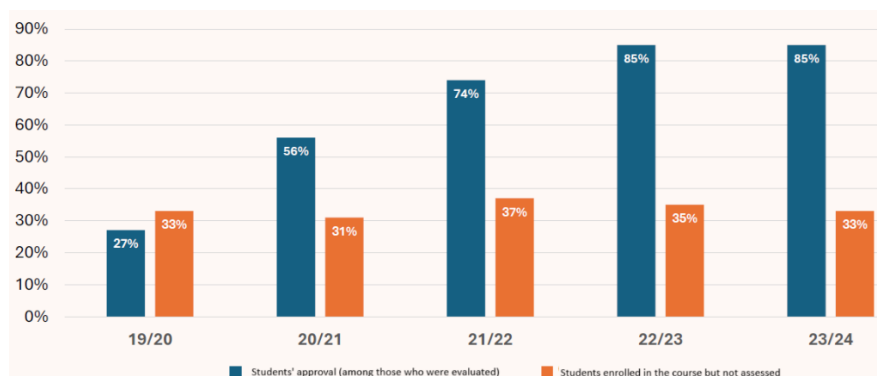


Figure 2. Evolution of the students' approval rates and enrolment without assessment rates.

Now, if we look at the percentage of students enrolled in the course but not assessed (represented by the orange bars in Figure 2), we can use this as a rough indicator of the dropout rate. The data shows that there isn't a consistent downward trend in this area. From 2019/2020 to 2020/2021, there was a slight dip from 33% to 31%. But then, in 2021/2022, it jumped back up to 37%, which was the highest during the analysed period. In the next two academic years (2022/2023 and 2023/2024), the percentage dropped again to 35% and 33%, respectively. This back-and-forth suggests that the link between the changes made in teaching and assessment methods and the dropout rate (as estimated by the percentage of students enrolled but not assessed) is more complex than we might have thought. There are also external factors at play, such as differences in the profiles of incoming students, economic or personal challenges they face, and changes in the overall academic environment of the institution, which could all impact the dropout rate. To really understand the trends in dropout rates for the Applied Mechanics course, we need to consider these factors alongside the data on teaching and assessment methods.

The improvement in student engagement and approval rates can be better understood when viewed through theoretical lenses. The flipped learning model and the diversified assessments align with Bloom's taxonomy, particularly targeting higher-order cognitive processes such as application, analysis, evaluation, and creation. These were evident in the use of peer discussion, problem-solving, and creative tasks like infographic and meme design. Moreover, the instructional approach closely reflects Kolb's experiential learning theory. Students progressed through concrete experiences (hands-on assignments), reflective observation (peer feedback and discussion), abstract conceptualization (content analysis through reading and videos), and active experimentation (applying knowledge in mini-tests and creative outputs). This experiential cycle supports a variety of learning preferences and likely contributed to the overall improvement in performance. These results also resonate with findings from (Freeman et al., 2014), who showed that active learning significantly enhances performance in STEM fields, and (Theobald et al., 2020), who found it can reduce achievement gaps among underrepresented students. By grounding the observed improvements in these educational theories and studies, the transformation of the Applied Mechanics course gains not only empirical but also pedagogical validation.

4 Conclusions

The review of teaching and assessment methods in the Applied Mechanics course over five academic years (2019/2020 to 2023/2024) reveals a significant transformation from a traditional, teacher-centred model to a more dynamic, student-focused learning approach. This shift has brought in innovative teaching techniques like flipped learning and a wider variety of assessment methods, giving students multiple avenues to demonstrate their knowledge and skills.

Looking at the pass rates and the percentage of students who enrolled but weren't assessed during these years, we noticed a significant drop in the latter starting from 2021/2022. This decline coincides with the introduction of more frequent and diverse assessments, beginning with two tests and later expanding to four mini-tests. This trend suggests that varying assessment methods may have boosted student engagement, leading to a lower dropout rate. However, even with these encouraging results, simply switching to student-centred teaching methods and diverse assessment strategies might not be enough to ensure significant improvements in student performance. Other factors, like the quality of instructional materials, the complexity of the curriculum, and the availability of teaching support, are also vital in shaping pass rates.

To effectively implement active learning in other courses, it's essential to adopt a gradual and well-thought-out approach. Rather than overhauling everything at once, it's more effective to introduce new methods incrementally, allowing both students and teachers to adapt comfortably. To kick things off, using engagement techniques like interactive questioning and group problem-solving is a fantastic way to get started. These approaches really encourage students to participate actively, which helps them understand the material better and feel more involved. Once students become comfortable with interactive learning, you can gradually introduce methods like flipped learning. This approach allows students to take on some of the learning responsibility themselves, letting them dive into topics at their own pace before coming together for class discussions and activities. Tools like Padlet or online discussion forums can help keep those conversations going even outside the classroom. Collaboration plays a crucial role in this whole process. However, to make sure everyone participates fairly and contributes meaningfully, it's crucial to design group activities carefully.

As teaching strategies evolve, so should assessment methods. Moving away from a single high-stakes final exam to a system of continuous assessment — like quizzes, mini-tests, and interactive assignments — gives students regular feedback and a clearer picture of their progress. You can also incorporate participation-based assessments, rewarding students for their involvement in discussions and problem-solving tasks.

Implementing these changes brings challenges. Students might find it tough to follow unclear instructions, deal with time constraints, or keep up with the pace. To tackle these issues, teachers should provide clear guidelines, offer flexible deadlines, and setup support sessions to help students adapt to the new methods.

The success of these learning strategies shows that there's room for refining teaching tactics and expanding their impact by exploring even more methods. Key improvements could include regularly reviewing assessment components to prevent overwhelming students and balancing individual and group work to find the best approaches for various learning goals. Plus, adaptive learning technologies can offer personalized support, adjusting content to meet students' needs and learning speeds. Positive experiences with flipped learning and interactive assessments show that there's a real opportunity to apply these methods across various subjects. That said, it's crucial to plan carefully, especially when dealing with larger classes. While using active learning techniques in theoretical courses can be tricky, they also provide a great chance to engage students with challenging concepts. Training plays a vital role in making these approaches work. Workshops and professional development sessions can equip educators with the tools they need to implement and adapt active learning strategies effectively. By broadening the use of different teaching methods, we can significantly boost student engagement and improve learning outcomes. A blended approach that mixes traditional lectures with active techniques like project-based learning, case studies, and problem-based learning can cater to various learning styles. Adding gamification elements, such as quizzes and competitive team challenges, can also enhance motivation and participation. Plus, trying out inquiry-based learning, where students dive into concepts through research and hands-on experimentation, can foster critical thinking and problem-solving skills. By continuously evolving and diversifying our teaching methods, we can create dynamic learning environments that truly support student success.

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Enhancing Pedagogical Architectures through the use of ChatGPT

Crediné S. de Menezes¹, Rosane Aragón¹, Andromeda G. M. de Campos², Alberto N. de Castro Junior³

¹ Federal University of Rio Grande do Sul, Brazil

² Federal Institute of Education, Science and Technology of Espírito Santo, Brazil

³ Federal University of Amazonas, Brazil

Email: credine@gmail.com, rosane.aragon@gmail.com, andromeda.campos@ifes.edu.br, alberto@icomp.ufam.edu.br

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Abstract

One of the fundamental aspects of implementing new Pedagogical Architectures for Networked Learning (PANL) is proper computational support. According to studies by the proponents of PANL, such support can be significantly enhanced through the use of artificial intelligence technologies, benefiting both students and mediators. Specialized literature identifies various PANL proposals that have already been applied and evaluated in undergraduate and graduate courses. However, the implementation of AI-based solutions still faces challenges, such as the lack of suitable integration into educational applications. Recently, OpenAI introduced ChatGPT to the public, a chatbot incorporating various intelligent functionalities capable of supporting this integration. In this article, we analyze the contribution of ChatGPT-4o in supporting the PANL "Debate of Theses". We present a debate involving five students from a Brazilian public university. In the experiment, five scenarios (cases) were selected for analysis, and we discuss the specific contributions of ChatGPT-4o in each of them.

Keywords: Active Learning; Engineering Education; Pedagogical Architectures; Pedagogical Mediation.

1 Introduction

Pedagogical mediation plays a crucial role in learning, whether in formal or informal contexts. In schools, this work is primarily carried out by teachers or their assistants. In classrooms with a large number of students and limited time for individualized support, mediation is often hindered, which impacts the quality of learning outcomes.

In the constructivist framework, the roles of students and teachers are redefined. The student is placed at the center of the process, responsible for interacting with both the learning objects and peers. Meanwhile, the teacher assumes new roles, such as curator and mediator. This approach allows students to engage with diverse perspectives on the topic under study, contributing to a deeper understanding of the content.

Pedagogical Architectures for Networked Learning (PANL) (Menezes & Aragón, 2018) encompass pedagogies that can accommodate flexible, adaptable, and malleable didactics suited to various thematic approaches (Menezes et al., 2021). They are based on the premise that understanding requires the creation of specific cognitive tools. This construction is fostered when individuals find a space for autonomous action and joint construction (Menezes, et. al, 2021).

Generative artificial intelligence (GenAI), which has emerged in recent years, has shown significant potential to enhance education. In our research, we have focused on exploring its use as a tool to support the mediation of learning process as foreseen in (Panceri, 2016).

This study presents a teaching experiment using the pedagogical architecture "Debate of Theses." We employed ChatGPT to analyze various aspects of the texts produced, aiming to evaluate the potential contributions of this technology in supporting teachers' mediation efforts.

2 The Pedagogical Architecture *Debate of Theses*

Within the framework of cognitive ecology, technologies are seen as components that significantly alter contexts and forms of interaction; however, their meanings and modes of use are also shaped by other components (Aragón, 2016). Thus, digital technologies are understood as part of a micro-ecosystem, always intertwined with pedagogical ideas and educational contexts (Jackson, 2013). If technologies are not conceived as integrated elements, there is a risk of imagining that simply providing them—without changing conventional pedagogical ideas—will suffice for learning to occur, or alternatively, of underestimating them by considering their use dispensable (Aragón, 2016).

In pedagogical architectures, mediation plays a fundamental role in implementing a policy that fosters debate, research, and reflection. However, mediation does not need to be limited to the teacher. While the teacher will not relinquish their role as mediator, this mediation can be performed at different levels, with the active participation of peers in a distributed manner.

The primary purpose of distributed mediation is to strengthen more horizontal and cooperative relationships among participants (Parrat-Dayán, 2007)(Camargo et al, 2012). These participants may find valuable opportunities to exercise leadership and take responsibility within their peer groups. Considering our educational culture, which tends to centralize educational processes around the figure of the teacher, this role must be learned by students—a process that can greatly benefit from engaging in collective debates within the framework of these architectures. Pedagogical architectures propose an organization of work that shifts learners to a more active position, in which they also assume mediation roles, which, in turn, are refined through practice. An example of the use of distributed mediation is the Thesis Debate architecture (Aragón, 2016).

This architecture aims to develop or deepen knowledge on a given subject cooperatively. The mediator selects a set of statements, referred to as theses, to serve as a basis for the structured debate. What we call a debate, in this case, is an asynchronous dialogue organized in stages. Initially (Stage I), each participant presents their stance (agree, disagree, partially agree, or partially disagree), supported by an argument. In Stage II, each participant reviews the argument of two fellow debaters and, in return, has their own argument reviewed by two peers. Stage III is dedicated to each participant's reflection on the reviews received. In Stage IV, each participant revisits their initial argument to (re)construct their stance, concluding with the new argumentation. The continuation of the activity can proceed in various ways, at the discretion of the mediator in cooperation with the participants.

3 Generative Artificial Intelligence

Generative artificial intelligence (GenAI) has evolved rapidly, demonstrating significant advancements in content creation, problem-solving, and personalized learning experiences. AI models have become increasingly sophisticated, integrating chain-of-thought reasoning, multimodal capabilities, and enhanced contextual understanding. AI-driven tools are now widely adopted across industries, including education, where they assist teachers in curating content, assessing student progress, and—as explored in this article—facilitating mediation in learning environments.

GenAI operates on advanced machine learning (ML) architectures, primarily deep learning models such as transformers and diffusion models. These architectures enable AI to generate coherent text, images, and other media by identifying patterns from vast datasets, processed through immense computational power. Among the fundamental technical components of GenAI are Large Language Models (LLMs), such as OpenAI's GPT series and Google's Gemini models, which leverage billions of parameters to process and generate human-like

text. These models employ self-attention mechanisms to understand context and improve response accuracy (Storey, 2025)(Floridi, 2023).

AI systems are evolving beyond simple pattern recognition toward agentic reasoning, where models actively "think" through complex problems before responding. This capability further enhances AI-driven pedagogical mediation by fostering deeper engagement and more meaningful student interactions. As AI becomes increasingly integrated into education, researchers emphasize bias mitigation and ethical AI development to ensure fair and responsible use. Techniques such as algorithmic transparency and human-in-the-loop oversight help maintain AI reliability (Storey, 2025).

These advancements position generative AI as a powerful tool for pedagogical mediation, enabling personalized learning feedback and improving student-teacher interactions.

4 The Experiment

Text production in a Debate of Theses (Aragón, Menezes, & Castro, 2022) is rich and extensive. To handle different analyses of the debate results, the support of computational assistants is often necessary.

To demonstrate the type of intelligent support that ChatGPT can offer, we conducted a Debate of Theses with the participation of three undergraduate students from a Production Engineering program, all of whom were Scientific Initiation scholarship holders at a public institution in Brazil. The debate took place in an online digital environment specifically developed for activities of this nature (<http://debatedeteses.com.br/>). Table 1 presents a description of the debate conducted.

Table 1. Description of the Experiment

Debate – Project Management

Description: Learning about project management in a cooperative way. Debate asynchronously with your peers to deepen your understanding of project management.

Mediator(s): (omitted for review)

Participants: 5 debaters

Theses: 3 theses were created: (i) Scope changes will not harm the project; (ii) If the team has already had a successful experience in a project, then the next project will also succeed if they follow the same steps; (iii) If a project is on schedule and within budget, it will achieve good results.

GENAI used for analysis: ChatGPT 4o

The queries conducted are part of a selection of features that may contribute to supporting the mediation of a debate. After each query was presented, we held a brief discussion on the result provided by the generative AI considered (ChatGPT 4o).

To illustrate the different aspects of the texts produced, we selected "Thesis (i): Scope changes will not harm the project" along with the contributions of three debaters. Our aim was to evaluate potential contributions of technology in supporting the teacher's mediation work. To this end, we identified specific functionalities of ChatGPT that could assist in facilitating debate mediation. After presenting each case, we conducted a brief discussion on the results provided by ChatGPT-4o.

Case 1: Coherence Between the Argument and the Thesis

Context: Consider the initial argument of Participant 1 (P1) regarding Thesis 1: <i>The change in project scope, by itself, is not necessarily harmful; it can indeed negatively affect the project, especially if the goal increases its complexity and/or the deadline is moved closer to the present moment. However, the opposite cases can benefit a project that would otherwise be delayed or lack resources.</i>
Request: Analyze the correlation of the argument in relation to the content of Thesis 1.
ChatGPT Response: Yes, the initial argument text shows a good correlation with the proposed thesis because it directly discusses the consequences (negative or positive) of scope changes on the project, which is the subject of the thesis.
Discussion: The coherence between the argument and the thesis, as identified by the GenAI, may indicate to the mediator that there is no need for intervention regarding the initial positioning. However, in cases where incoherence is detected, the mediator can perform problem-posing interventions to guide the participant in seeking coherence, which is important for the continuity of the debate.

Case 2: Authenticity of Participants' Argumentations

Context: Consider the initial argumentations of the other two participants: Initial argumentation of Participant P2: This type of change affects what is scheduled to be executed, which is clearly a problem for the organization of the project as a whole. Initial argumentation of Participant P3: Although scope changes happen very frequently, this requires a great deal of flexibility from those executing the project. Therefore, depending on the variables, the team may not be able to adapt, and the project may suffer negative consequences—such as compromising the delivery deadline or increasing its cost. For this reason, it is important for the manager to anticipate the factors that may influence the execution of the project and to plan its scope while already considering possible future changes.
Request: Verify whether there is any evidence of plagiarism among the initial argumentations of the three participants.
ChatGPT's response: There is no evidence of plagiarism among the initial argumentations of the three participants. Although all address the same topic and naturally share some common ideas (impacts of scope changes), the texts are distinct in form, structure, and development.
Discussion: A recurring concern among teachers is the possibility that students may reproduce already published texts or even consult a Generative AI tool. In this case, rather than being a source of plagiarism, AI can serve as a means of verifying authorship. The use of the Thesis Debate architecture, particularly in its initial argumentation stage, requires participants to express their ideas, reflecting their prior knowledge. To assess whether participants' knowledge has progressed, it is imperative that the initial stance be authentic.

Case 3: Contributions of the Reviewers

Context: Now consider the text from the second reviewer (R2) to Participant P1: <i>The point presented is consistent with what is stated in the thesis, but it was necessary to reread it several times to understand what the argument was trying to convey—especially the last sentence.</i>
Request: Analyze the contribution to P1's reflections with a view to deepening their analysis, as well as the cordiality of the text.

ChatGPT's response: R2's review is polite and provides a relevant comment regarding textual clarity. However, it lacks deeper analytical input to help P1 strengthen their argument in terms of content, not just form.

Discussion: For knowledge advancement within the proposed pedagogical architecture, it is essential that exchanges (dialogues) occur among participants. The confrontation of ideas requires justification of what has been argued, and when such justifications are insufficient, doubts arise. Through actions taken to resolve these doubts (such as readings, reflections, etc.), participants reconstruct their prior knowledge, leading to new ideas. Considering the importance of interindividual exchanges, the mediator intervenes to ensure that this dynamic unfolds within the timeframe established for this stage and provides quality materials to support the debate among participants.

Case 4: Evolution of the Argumentations

Context: After interacting with their peers, participants present a new stance and argumentation for each thesis in Stage 4.

Still considering Thesis 1, below are Participant P2's stance and argumentation in Stage 1 and Stage 4.

Stage 1

Stance: Partially disagree.

Argumentation: Although scope changes happen very frequently, this requires a great deal of flexibility from those executing the project. Therefore, depending on the variables, the team may not be able to adapt, and the project may suffer negative consequences—such as compromising the delivery deadline or increasing its cost. For this reason, it is important for the manager to anticipate the factors that may influence the execution of the project and to plan its scope while already considering possible future changes.

Stage 4

Stance: Partially disagree.

Argumentation: Although scope changes may be inevitable, they require a great deal of flexibility. Therefore, depending on the variables, the execution team may not be able to adapt and may face negative consequences—for example, affecting the delivery deadline and/or increasing the project's cost. Thus, it is up to the project manager, during planning, to consider the factors that may influence its execution, incorporating the observed information into the project scope. This makes it possible to maintain greater control over the project and avoid changes in the future.

Request: Analyze the evolution of their argumentation.

ChatGPT's response: The participant maintained their stance and the central ideas that scope changes can be problematic and require managerial attention. In Stage 4, there was qualitative improvement by adding a more practical and explicit recommendation to incorporate these analyses into the scope itself. The final argumentation is more coherent and flows better, although a small grammatical adjustment is needed in the opening.

Discussion: Considering the challenges that mediators typically face in mapping each participant's learning trajectory—especially in groups with a larger number of participants—AI can play a facilitating role in monitoring the process and providing support for assessment. With this support, the mediator can carry out interventions to improve the quality of the argumentations, such as suggesting reference materials.

Case 5: Convergences and Divergences of the 3 Participants

Context: Now consider the final stance and argumentation of the 3 participants regarding Stage 4.

Participant P1

Stance: Partially disagree.

Argumentation: The change in the project's scope, by itself, is not necessarily harmful; it can indeed negatively affect the project, especially if the goal increases its complexity and/or the deadline is moved closer to the present moment. However, the opposite cases can benefit a project that would otherwise be delayed or lacking resources.

Participant P2

Stance: Partially disagree.

Argumentation: This type of change affects what is scheduled to be executed, which is clearly a problem for the organization of the project as a whole. However, scope changes can be made to adjust the project's progress in light of unforeseen events and possible improvements.

Participant P3

Stance: Partially disagree.

Argumentation: Although scope changes may be inevitable, they require a great deal of flexibility. Therefore, depending on the variables, the execution team may not be able to adapt and may face negative consequences—for example, affecting the delivery deadline and/or increasing the project's cost. Thus, it is up to the project manager, during planning, to consider the factors that may influence its execution, incorporating the observed information into the project scope. This makes it possible to maintain greater control over the project and avoid future changes.

Request: Analyze the convergences and divergences in the argumentation.

ChatGPT's response: All participants maintain a generally convergent line of reasoning: scope changes are generally problematic but should not be viewed as invariably harmful.

P3 stands out by offering a more technically detailed solution (proactive planning and control), while P1 and P2 are simpler and more descriptive.

P2, although more concise, introduces a new point in Stage 4 (the acceptance of changes as adjustments), while P1 almost entirely repeats their initial argumentation.

Discussion: In this case, AI support involves mapping both individuals and the group regarding the knowledge generated in the debate. In this way, it assists the mediator in assessing both individual learning and the outcomes of the architecture's application. Furthermore, it can indicate to the mediator aspects of the debated topic that may need to be revisited.

5 Discussion

This investigation was informed by pedagogical practices conducted at basic, undergraduate, and graduate levels. Depending on the number of participants, the mediation process is often hindered by time constraints, limiting the observation of more abstract aspects of students' reasoning. A significant portion of instructional time is typically devoted to analyzing structural elements, such as thematic deviations, redundant arguments, and basic textual organization.

The experiment reported here demonstrated the feasibility of developing computational filters based on carefully designed natural language prompts. These tools facilitate the analysis of preliminary textual features and support pedagogical mediation at a conceptual level, thereby fostering the identification of students' intellectual development.

In the specific context of a thesis debate, the goal is to provide formative feedback aimed at enhancing students' awareness of the discursive implications of a thesis, while also promoting engagement with multiple perspectives. These deeper insights are often constrained by the need to first address structural issues, delaying more meaningful semantic interpretation. The findings suggest that GenAI can assist in filtering preliminary aspects of the analysis, allowing educators to focus on higher-level conceptual mediation.

Based on the findings of this study, a new version of the "Thesis Debate" platform is being developed to incorporate functionalities that strengthen and better support the role of the mediator.

6 Concluding Remarks

In this article, we discussed some of the possibilities that so-called Generative Artificial Intelligences demonstrate for contributing to education, both as intelligent support for teacher mediation and for distributed mediation. We also provided examples and presented situations in which GenAI acts as a companion to the student. It is not about replacing the teacher's mediation or distributed mediation, nor about substituting students' learning efforts, but rather about using GenAI as an element that forms part of the students' learning ecosystem, enabling "dialogues" that may stimulate cognitive development.

Regarding the monitoring and analysis of learning, we observe that GenAI can play a role, as it allows the teacher to organize the interactions that occur among students and between students and the teacher, in addition to supporting the monitoring of individual and group development. Among other possibilities, we highlight that GenAI can reveal gaps in students' knowledge, inconsistencies in their arguments, and conceptual changes (learning) that unfold during the course of pedagogical architecture.

It is also important to highlight that the analyzed situations represent moments during or between the stages of the Debate of Theses, where the mediator can contribute to the quality of the discussion. Of course, many other situations anticipated in Panceri (2016) still need to be examined, particularly regarding support for collective synthesis. This report is part of an ongoing investigation aimed at developing new functionalities for the <http://debatedeteses.com.br/> platform to support Networked Learning Pedagogical Architectures (PANL).

The ethical challenges associated with the development and implementation of artificial intelligence must not be underestimated (Floridi, 2025). The proposal presented in this article was developed alongside ethical reflections and precautions that considered the inherent biases and limitations of AI. Measures were taken to critically analyse the responses generated by the AI, with the aim of ensuring their appropriateness and evaluating their potential to support teachers in their pedagogical mediation. This, therefore, is not a naive use of AI, but a deliberate effort to explore ways of employing it to enhance educational practices.

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Engineering Ethics Education Bingo 1.0

Shannon Chance^{1,2}, Mike Murphy¹, Celina P. Leão³, Mircea Tobosaru⁴, Mary Nolan^{5,6}

¹ TU Dublin, Ireland

² University College London, UK

³ ALGORITMI Research Centre, Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal

⁴ University Politehnica Bucharest, Bucharest, Romania

⁵ Atlantic Technological University Sligo, Ireland

⁶ University College Dublin, Ireland

Email: shannon.chance@tudublin.ie, mike.murphy@tudublin.ie, cpl@dps.uminho.pt, mircea.tobosaru@gmail.com, mary.nolan@atu.ie

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Abstract

This paper introduces Engineering Ethics Education (EEE) Bingo 1.0, an active learning tool designed to support ethics education among engineering educators. Drawing inspiration from game-based learning, EEE Bingo provides a playful yet purposeful framework for exploring diverse pedagogical approaches in engineering ethics. The game stimulates discussion and reflection on the alignment between ethical issues and suitable teaching methods, promoting greater pedagogical awareness and collaboration. This paper outlines the motivation behind the game, its structure and rules, and illustrative examples. EEE Bingo encourages critical engagement with teaching strategies, reinforcing the importance of contextualized, interdisciplinary, and reflective ethics education.

Keywords: Active Learning; Engineering Ethics Education; Game-Based Learning; Pedagogical Methods; Interdisciplinary Approaches.

1 Introduction

In recent years, engineering education has increasingly embraced active and experiential learning strategies to better engage students and higher education institutions with complex ethical and professional issues. One promising approach is game-based learning, which leverages structured play to stimulate critical thinking, collaboration, and reflective practice. Game-based environments help learners explore and make sense of complex issues by engaging in cycles of decision-making, feedback, and reflection, often resulting in deeper cognitive and affective engagement (Cloude et al., 2021). These approaches reflect a growing interest in applying playful formats to serious learning contexts, aligning with broader pedagogical trends emphasizing creativity, participation, and reflective dialogue.

Using games to teach engineering ethics has gained visibility as an alternative to more traditional, theory-heavy approaches. Lloyd and van de Poel (2008) argue that rule-based instruction or case studies often fail to engage students emotionally or situationally. To address this, they developed an enhanced version of the Delta Design simulation game, placing students in interdisciplinary design teams where they must navigate conflicting goals and real-time decisions. This immersive approach creates space for authentic ethical reflection and exposes students to moral complexity and distributed responsibility.

Similarly, Goetze (2022) presents an approach that enhances engineering students' engagement with ethical reasoning by simulating decision-making in complex scenarios through role-playing games. This method encourages learners to experience ethical dilemmas first-hand, promoting deeper understanding and reflection.

These experiential and interactive models resonate with the pedagogical vision behind Engineering Ethics Education (EEE) Bingo, which we launch publicly with the publication of this conference paper. While Delta Design and role-playing simulations embed students within ethically charged scenarios (Lloyd & van de Poel,

2008), EEE Bingo 1.0 engages *engineering educators* in thinking critically about ethics pedagogy—specifically, how various teaching methods align with different ethical issues in engineering contexts. It invites playful yet thoughtful exploration of educational strategies, helping educators reflect on how their choices impact students' ethical awareness and development. Our team aims to refine the game over time, iteratively upgrading it as we deploy it with various target groups of engineering educators.

The game is intended to be included as one part of workshops on the topic of integrating ethics (e.g., social and environmental justice, ethical theories and dilemmas) into engineering teaching, as the tool's high-speed nature is geared toward brainstorming rather than slower contemplation. Specifically, we, the designers, envision that this bingo tool could be played at the opening of a workshop and followed by slower-paced, guided activities to help the workshop participants generate viable plans for integrating ethics education into their own engineering classrooms (e.g., see Chance, 2024; Chance & Direito, under review).

Therefore, the present paper introduces EEE Bingo 1.0 as an innovative, low-tech, and participatory tool designed to stimulate discussion and critical reflection among educators regarding pedagogical approaches and ethical dimensions relevant to engineering education. The authors welcome feedback and suggestions for further refinement.

2 Motivation

Content and themes for the game have been drawn from *The Routledge International Handbook of Engineering Ethics Education* (Chance, Børsen et al., 2025), which provides readers with a map of themes, topics, and arguments in the field of EEE (Chance et al., 2024). Among its contributions, Section 4, on Teaching Methods in Engineering Ethics Education, is particularly relevant to this game due to its focus on contemporary pedagogical methods. The section provides conceptual grounding and practical insights into how ethics can be more effectively taught in engineering programs.

The overview of section 4 (Martin, 2025) highlights the importance of diversifying pedagogical approaches to better connect with learners in meaningful and context-sensitive ways. The teaching methods presented across the chapters include a detailed literature review producing an overview of best practices (Polmear et al., 2025) and chapters focused on using case studies (Herzog et al., 2025), problems via challenges and problem-based learning (Routhe et al., 2025), value-sensitive design (Gammon et al., 2025), service learning and humanitarian engineering (Daniel et al., 2025), arts-based methods (Hitt et al., 2025), and reflective approaches and dialogical approaches (Marin et al., 2025). Each of these methods offers distinct pathways to student engagement and ethical development, yet both Polmear et al. (2025) and Martin (2025) emphasize that they are not isolated strategies. Rather, they overlap, intersect, and complement one another, reflecting the real-world complexity of ethical issues in engineering. As Martin notes, “Educators exploring the applicability of EEE methods may find that multiple approaches described by our authors hold relevance. Indeed, there are many overlapping themes” (p. 339).

Martin's (2025) overview encourages educators to move beyond static, one-size-fits-all models of teaching ethics and instead embrace pluralism, creativity, and responsiveness in pedagogy. This aligns with the goals of the present work, which introduces EEE Bingo 1.0 as a playful yet purposeful method to explore and reflect on diverse teaching approaches in engineering ethics. The objective of this paper is to present an engaging and fun way for educators to examine various pedagogical strategies alongside the types of ethical issues for which they might be most appropriate. By bringing together educators in an active, low-tech, and collaborative setting, EEE Bingo 1.0 seeks to embody the spirit of integration and exploration that Martin advocates for in her overview of teaching methods.

3 Game Design and Implementation of EEE Bingo 1.0

This section describes the key features, rules, and practical elements of implementing EEE Bingo 1.0 in an educational setting. The game aims to create an engaging environment for educators to explore how ethical issues intersect with pedagogical strategies across various engineering disciplines.

3.1 EEE Bingo 1.0 Characteristics

When played as a normal bingo game, EEE Bingo 1.0 will generally have a winner unless the time allocation is too short for the game to fully play out. The purpose of the game is to get participants into a frame of mind in which fruitful discussion on teaching methods for target outcomes can be explored.

- **Target Audience:** Academics and faculty involved in EEE who are seeking to understand teaching methods that might be suitable for their particular use and circumstance. The target audience is not engineering students but rather their teachers.
- **Players:** Although individuals can play the game, more benefits will be derived if the participants break into teams of 3 or 4. The minimum number is two teams, and the maximum number is open-ended.
- **Equipment:** The game is low-tech; the only equipment required are pre-printed EEE bingo cards, pens (not pencils, to prevent erasing), and the sheet of prompts for the Facilitator (as presented in the Appendix).

3.2 Structure of EEE Bingo

The game is played systematically:

Step 1: Each Team receives an EEE Bingo card. An example blank card is shown in Figure 1. The order of items in each column and each row varies from card to card, such that each group has a different card. The object is to fill in six adjacent boxes to make a single line (across, down, or diagonal from corner to corner) and be the first team to do this and to call "Bingo!".

	Value-Sensitive Design	Reflection & Dialogue	Case Study	Service Learning	PBL	Arts-Based
Mechanical Engineering						
Bio-Medical Engineering						
Civil Engineering				Urban Planning		
Software Engineering						
Chemical Engineering						
Electrical / Electronic Engineering						

Figure 1. Full Blank EEE Bingo 1.0 Card

Step 2: The Facilitator explains that the rows relate to the specific engineering disciplines discussed in Section 3 of the Handbook (Chance, Børsen et al., 2025), while the columns refer to the various active pedagogical approaches described in Section 4 of the Handbook.

In Figure 1, we have filled in one example cell to illustrate what we intend the teams to do. Every card would have the cell at this same intersection filled in at the outset of the game (specifically, where “Service Learning” meets “Civil Engineering”). This is a free space, constituting an example and a gift to the team to get them rolling.

Step 3: To illustrate, the facilitator will explain: “Find the cell where “Service Learning” meets “Civil Engineering”. We have filled this one in for you. Your team would have identified a way to combine these two in an activity to teach engineering students about ethics that uses “Service Learning” in the context of “Civil Engineering”, coming up with something like this:

Our topic is **Urban Planning**, and we are asking the students to collaborate with a local community to design an inclusive urban space that addresses ethical concerns of accessibility, environmental justice, and equitable resource distribution.

After defining the activity, the team would write the topic of “Urban Planning” in the applicable cell.

Step 4: The Facilitator answers any immediate questions from Participants.

Step 5, shorter option A: Having explained the rows and columns, the Facilitator then reads out an example of an issue with ethical dimensions as provided in Appendix A. The prompts should be drawn from a hat to ensure randomization. The Participants have a short time (e.g., 20 seconds) to discuss within their Team and decide in which cell of the EEE Bingo 1.0 card the example would best fit. They write the example into the appropriate cell of the bingo card.

Step 5, longer option B: Having explained the rows and columns, the Facilitator then calls out an intersection of one method and one discipline. Again, the combinations should be drawn from a hat to ensure randomization. The Participants have a measured time (e.g., 120 seconds) to discuss within their Team and decide in which cell of the EEE Bingo 1.0 card the example would best fit. They write the example into the appropriate cell of the bingo card.

Step 6: Play continues until one Team has a complete row, column, or main diagonal filled. They then yell ‘BINGO’, and the game stops.

Step 7: The Team that yelled Bingo must then explain why they placed each example in the box that they did. The other teams and the Facilitator now have the opportunity to challenge the team’s interpretation.

Note that there are no definite/rigid/hard ‘correct’ answers regarding the pedagogical methods, and so an argument can likely be made for any of the pedagogical columns. This is not quite as easy for the disciplinary rows, as it is more difficult (but not impossible) to argue that, say, cybersecurity is an example of a mechanical engineering ethical issue.

Step 8: After BINGO has been called, or the game has run out of time, the Facilitator will draw the game element to a close and move the group back to a collective discussion and reflection on the types of pedagogy and the disciplines that they might suit them.

Figure 2 illustrates the overall flow of the EEE Bingo game, from setup to final reflection, offering a visual summary of the main stages described in this section.

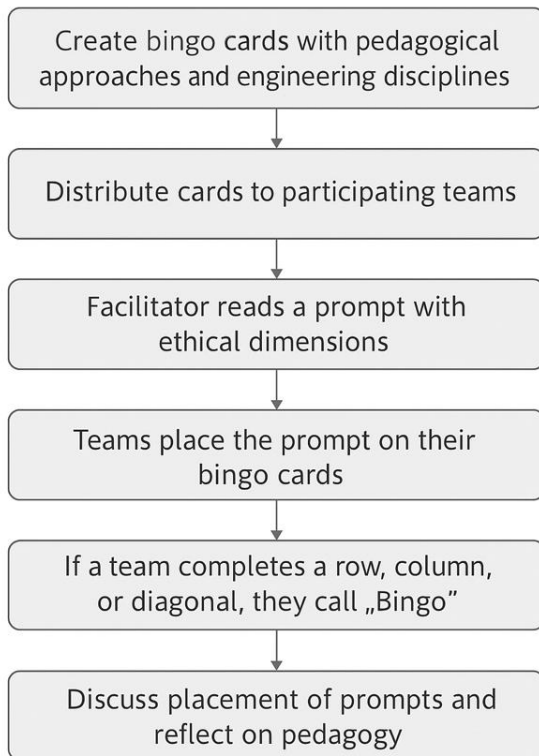


Figure 2. Flowchart of the main steps using **Step 5, shorter option A** to play the EEE Bingo 1.0

3.3 Prompts

For **Step 5, shorter option A** the Facilitators will need to prepare prompts in advance or draw them randomly. These should be short scenario descriptions that embed ethical issues in specific disciplines. Appendix A provides examples. For this short option, it would be best to make one example per intersection to draw from the hat. Here is one example:

This topic is **Cybersecurity**, and the activity is to ask student teams to develop a security solution for a real-world scenario while analysing and addressing the ethical implications of privacy, data collection, and surveillance technologies. Please find where this fits on your bingo card and write Cybersecurity in the box.

For **Step 5, longer option B**, the Facilitators will need to prepare a way to randomly select the combination of teaching method and discipline to call.

3.4 Completed Example

Figure 3 shows a completed example that could suffice as a winner. A team needs to complete a sequence of six in a row, and as shown, the Case Study column is complete. This completed bingo card demonstrates how diverse ethical topics (e.g., Smart Grid Privacy, Infrastructure Resilience, Sustainable Manufacturing, Algorithmic Fairness, Environmental Justice, and Assistive Technology) can be matched with pedagogical approaches (Case Study) across various disciplines.

	Value-Sensitive Design	PBL	Case Study	Service Learning	Arts-Based	Reflection & Dialogue
Electrical / Electronic Engineering	Renewable Energy		Smart Grid Privacy			Sexist imagery and language
Civil Engineering			Infrastructure Resilience	Urban Planning		
Mechanical Engineering			Sustainable Manufacturing			
Software Engineering		Cybersecurity	Algorithmic Fairness			
Chemical Engineering			Environmental Justice		Green Chemistry	
Bio-Medical Engineering			Assistive Technology Access			

Figure 3. An Example “Winning EEE Bingo 1.0 Card”

Note that for another way to make the game move along a little faster, a card similar to that in Figure 3 can be used, in which a number of boxes are already completed.

3.5 Populating the Game

To populate such a game, you can ask an AI assistant like Claude to help, using prompts like:

Can you help me briefly describe in one sentence a possible assignment on [Urban Planning], using [Service Learning] to explore ethics in [Civil Engineering] without saying the words ‘service learning’ or ‘civil engineering’?

What would be a good topic for engineering students to study ethics using [Case Studies] in [Electrical and Electronic Engineering]? I need a topic, and a description like this for it, using the new info: “The next topic is Urban Planning, asking students collaborate with a local community to design an inclusive urban space that addresses ethical concerns of accessibility, environmental justice, and equitable resource distribution. Please find where this fits on your bingo card and write Urban Planning in the box.

We provide example results in Appendix A.

3.6 Implementation and Feedback

Although this version describes the conceptual framework and structure, future iterations will include testing the game in professional development workshops and classrooms. Feedback will be collected to assess the clarity of instructions, engagement levels, and potential adaptations.

4 Conclusion

This paper presents Engineering Ethics Education Bingo 1.0 as an innovative, engaging, and flexible tool to foster reflection and conversation around pedagogical strategies in engineering ethics. By drawing from active learning theory, game-based design, and the interdisciplinary nature of engineering ethics education, EEE Bingo 1.0 offers a playful approach to deep educational reflection. Future work will include piloting the game with educators and refining prompts and structure based on feedback.

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Appendix A: Example Prompts Generated by Claude

Below, we provide a set of example bingo prompts generated by the AI assistant named Claude, using the requests structured this way:

Can you help me briefly describe in one sentence a possible assignment on [Urban Planning], using [Service Learning] to explore ethics in [Civil Engineering] without saying the words 'service learning' or 'civil engineering'?

What would be a good topic for engineering students to study ethics using [Case Studies] in [Electrical and Electronic Engineering]? I need a topic, and a description like this for it, using the new info: "The next topic is Urban Planning, asking students collaborate with a local community to design an inclusive urban space that addresses ethical concerns of accessibility, environmental justice, and equitable resource distribution. Please find where this fits on your bingo card and write Urban Planning in the box.

For **Step 5, shorter option A**, it would be best to make one example per intersection to draw from the hat. It would be a good idea to check the relevance of Claude's suggestions either manually or perhaps using another AI tool like Notebook LM.

The next topic is **Smart Grid Privacy**, asking students to examine real-world implementations of smart electricity infrastructure while addressing ethical concerns regarding data privacy, security vulnerabilities, equitable access, and surveillance implications across diverse communities. Please find where this fits on your bingo card and write Smart Grid Privacy in the box.

- The next topic is **Infrastructure Resilience**, asking students to analyse existing public infrastructure projects while addressing ethical concerns regarding equitable resource allocation, disaster preparedness, climate adaptation, and prioritizing vulnerable communities in design decisions. Please find where this fits on your bingo card and write Infrastructure Resilience in the box.
- The next topic is **Algorithmic Fairness**, asking students to evaluate real-world automated decision systems while addressing ethical concerns regarding bias detection, transparency, accountability, and the impact of algorithmic decisions on marginalized communities. Please find where this fits on your bingo card and write Algorithmic Fairness in the box.
- The next topic is **Environmental Justice**, asking students to investigate industrial chemical processes and waste management practices while addressing ethical concerns regarding community health impacts, pollution distribution, informed consent, and the disproportionate burden faced by disadvantaged populations. Please find where this fits on your bingo card and write Environmental Justice in the box.
- The next topic is **Assistive Technology Access**, asking students to examine the development and distribution of medical devices and prosthetics while addressing ethical concerns regarding affordability, healthcare disparities, inclusive design, and balancing innovation with equitable access across socioeconomic boundaries. Please find where this fits on your bingo card and write Assistive Technology Access in the box.
- This topic is **Cybersecurity**, asking student teams to develop a security solution for a real-world scenario while analysing and addressing the ethical implications of privacy, data collection, and surveillance technologies. Please find where this fits on your bingo card and write Cybersecurity in the box.
- This topic is **Urban Planning**, asking students collaborate with a local community to design an inclusive urban space that addresses ethical concerns of accessibility, environmental justice, and equitable resource distribution. Please find where this fits on your bingo card and write Urban Planning in the box.
- This topic is **Sustainable Manufacturing**, asking students to analyse real-world sustainable manufacturing practices to identify ethical challenges in resource conservation, waste reduction, and environmental impact throughout the product lifecycle. Please find where this fits on your bingo card and write Sustainable Manufacturing in the box.

Institutional Support for Active Learning: a case study in Portugal and Brazil

Ronara Cristina Bozi dos Reis¹, Diana Mesquita²

¹ Federal University of Itajubá, Itabira, Brazil

² Universidade Católica Portuguesa, Faculty of Education and Psychology, Research Centre for Human Development, Porto, Portugal

Email: ronara@unifei.edu.br, dmesquita@ucp.pt

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Abstract

The labor market has demanded technical and transversal competences from graduates. In higher education, these competences are developed and/or enhanced through activities related to active learning approaches, which places the student at the center of the learning process. Much has been written the importance of active learning for students' professional development. Less has been known about the institutional strategy that enables opportunities for students to develop such competences and prepare them effectively for their professional practice. This research proposes a case study as a methodological approach, considering two universities, Portugal and Brazil. The object of study is the relationship between active learning and professional practice in the context of higher education, considering the institutional initiatives that prevail in both countries. The main objective is to analyze, from an institutional perspective, how active learning contributes to the development of competencies in the context of higher education. The data was collected first by document analysis of the strategic plans of the studied institutions, followed by interviews with institutional stakeholders in both countries. Preliminary results suggest that institutional support is fundamental, indispensable, and necessary for active learning to fulfill its role as a tool in building competences for students' professional practice. Although there is discourse on active learning as a methodology for student protagonism, in the studied institutions, its adoption is more strongly linked to individual initiatives of teachers than to robust institutional support. It is possible to identify programs and projects in which the student is the protagonist in the institutions. However, this is related to the teacher's performance and not necessarily to institutional criteria that encourage the teacher to adopt active learning strategies as the main tool in building competences for students' professional practice.

Keywords: Active learning; Professional development; Institutional strategies.

1 Introduction

The labor market has demanded not only technical but also transversal competencies from graduates. In higher education, these competencies are developed and/or enhanced through activities related to active learning, which places the student at the center of their education.

This work argues that the institutional aspects that enable active learning as a tool for the professional practice of students in learning environments are crucial for the university's role as an agent of local transformation and promoter of innovations. The object of study is the relationship between active learning and professional practice in the context of higher education, considering the institutional initiatives that prevail in two countries: Brazil and Portugal.

The main objective is to analyze, from an institutional perspective, how active learning contributes to the development of competencies in the context of higher education. The research questions guiding the study are: what are the institutional initiatives that promote competencies in the professional practice of students? How, in particular, do active learning contexts, in their various educational settings, contribute to the development of these competencies?

2 Background

The university originated as an institution focused on teaching and pure research, later turning its attention to meeting the demands of society, which led it to engage with social actors such as industry and governments, in order to expand the production and application of scientific knowledge and obtain alternative sources of resources for its activities. In contemporary times, it has emerged as an entrepreneurial university (Ruffoni, Melo, & Spricigo, 2017).

In this entrepreneurial university, there is a reorganization of knowledge in response to an information and knowledge society that demands the same from the academic world, which still employs traditional techniques for knowledge construction. The compartmentalization of knowledge is not in line with the functioning of an information and knowledge economy, which suggests new forms of knowledge construction, such as interdisciplinarity and active learning (Finkelievich, 2007).

There are two trends that push in opposite directions: the progressive diversification and specialization of knowledge and the emergence of increasingly specific and up-to-date research and teaching; on the other hand, the academic world shows the urgent need to adapt to the interdisciplinary nature of the most important social problems, such as sustainable development, poverty reduction, new public health issues, among others (Finkelievich, 2007).

Vale (2012) emphasizes the fundamental importance of the close relationship between universities and companies. Or at least, they should maintain such a relationship. This relationship would primarily occur through knowledge transfer processes, making universities crucial agents in the generation of knowledge, especially through scientific research, benefiting local economies (Goddard & Vallance, 2013).

Etzkowitz & Leydesdorff (2000) proposed the triple helix model, which presents the relationships among the university, the firm, and the government, and their impacts on development. Two complementary perspectives can be observed: the institutional, which concerns the institutional arrangements between the three spheres, and the evolutionary, which understands each sphere as a subset that can modify the role it plays in the context in which it is inserted (Ruffoni, Melo, & Spricigo, 2017). As an agent of an innovation system, universities play a dual role: on one hand, they train specialized labor; on the other, they support and sustain scientific research, making the institutional agreements established between the university, the company, and the public sector, understood as central agents in the production of knowledge and innovation, fundamental (Ruffoni, Melo, & Spricigo, 2017).

Although there is convergence among authors regarding the role of the university as an agent of information, knowledge, and innovation, Rapini (2018) points out areas for improvement to address the weaknesses in the performance of universities: 1) generation of multidisciplinary knowledge; 2) reduction of internal university bureaucracy to favor broad cooperation; and 3) promotion of actions aimed at Development vis-à-vis the Entrepreneurial University.

These points are aligned with Fonseca (2019), who also identifies the following as limiting factors for the university's performance: a) limitations of financial, human, and time resources; b) complex bureaucratic processes; c) fragmentation of engagement channels; and d) inadequacy in performance evaluation.

The relationship between the university and society is compromised in the sense that the latter may not have access to the knowledge produced by the former. Social demands, from which scientific and academic research should originate, end up playing a secondary role when directing research efforts.

Goddard & Vallance (2013) assert that the location of universities in cities necessarily implies a relationship with other institutions that inhabit the place. Therefore, the relevance of academic practice for the territory in

which the agents of information, knowledge, and innovation work, live, and act as citizens is discussed. In the view of these authors, the university is an institution that establishes horizontal links – local social and institutional spheres – and vertical links – global flows of knowledge and people.

Finally, the university's role in the local reality lies in the fact that, institutionally, this agent of information, knowledge, and innovation has or should have the necessary and adequate tools, instruments, and mechanisms for the local establishment of knowledge. The university thus plays a dual role in the information and knowledge economy: it produces knowledge and trains the agents who produce knowledge. It is, therefore, a privileged actor. However, the effectiveness of its role is closely linked to the existence of a science, technology, and innovation policy, whether explicit or not, and to the possibility of social appropriation of the results of the investigations carried out.

Goddard & Vallance (2013) present the possibilities of relationships between teaching-research-extension in universities: teaching and research as the integration of academic activities; teaching-extension, due to the integration of academia with society and vice versa; research-extension, which can provide economic impact as it responds to societal demands. Aligned with these authors are Breznitz & Feldman (2012), who list the diversity of roles that can be associated with the university's performance, which goes beyond the effects of the classic teaching-research relationship: workforce development, partnerships for regional socioeconomic development, promotion of local entrepreneurship, greater integration between the agents of information, knowledge, and innovation in the university's locality. When thinking about public policies, there is the possibility of conducting research with the aim of providing support to public administration for the region's economic and social development. Finally, one can also think about cultural dynamism in the city and region and the effort towards the internationalization of this territory.

In this context of the university's central role as a producer of knowledge and a trainer of the workforce, active learning emerges as a tool that enables the fulfillment of the university's three missions – teaching, research, and extension – with the latter being emphasized as fundamental for the effectiveness of its role.

Active learning is not confined to the classroom. Felder & Brent (2009) discuss that active learning applies to a context where there is a problem, a question, or an inquiry, whose answer or solution can be constructed through reflection and discussion. This can occur in laboratories, companies, the local reality, and even in the classroom. Environments that enable active learning place the student as the protagonist in the construction of knowledge, equipping them with competencies such as communication, leadership, teamwork, and emotional intelligence. The teacher/mentor acts as a mediator who prepares students for their professional future (Christie & Graaf, 2015).

Much has been written about significant experiences related to active learning in the professional practice of students (Felder & Brent, 2009; Prince, 2004; Prince & Felder, 2006; Bonwell & Eison, 1991) and about evidence that active learning allows for the achievement of satisfactory educational outcomes (Freeman et al., 2014; Weiman, 2014; Lund & Stains, 2015; Theobald et al., 2020; Nguyen et al., 2021). However, little is known about how institutional strategies are adopted to favor the construction of competencies in students and prepare them for professional practice in the labor market.

This work argues that the institutional aspects that enable active learning as a tool for the professional practice of students in learning environments are crucial for the university's role as an agent of local transformation and promoter of innovations. Therefore, it investigates how the studied institutions promote, institutionally, initiatives that contribute to the professional practice of students, equipping them with transversal competencies, in addition to technical ones.

3 Methodology

This work is a fragment of a post-doctoral research and the results are still partial. Ten institutional personalities were interviewed, five from each of the institutions involved in the research, about the relationship between active learning and professional practice in higher education in the Portuguese and Brazilian contexts.

A case study was conducted following a qualitative approach with semi-structured interviews, followed by content analysis according to Bardin (2004). The identification of institutional actors was crucial for the results obtained so far, as they are directly involved with institutional aspects and have the power to make decisions and implement pedagogical innovations.

The data collection followed the following procedure: in the first set of questions, the interviewees were invited to describe their professional trajectory, which justified the choice of each of them; in the second set of questions, the interviewees discussed the relationship between active learning and institutional aspects/strategies, and finally, in a third moment, they were asked about the relationship between active learning and the professional practice of students.

The semi-structured interviews were transcribed and, following Bardin (2004), the responses were categorized into: 1) active learning and competencies; 2) active learning and institutional strategies; and 3) active learning and professional practice.

4 Results

Initially, all interviewees were encouraged to describe their professional trajectory.

All ten interviewees hold decision-making positions regarding pedagogical and institutional matters and, in this sense, can direct/choose strategic decisions for pedagogical innovations that affect the professional practice of higher education students. Another point to highlight is the fact that all of them have been or are involved in teaching activities, administrative activities, and institutional decision-making positions, emphasizing the statement of one of the interviewees: "everything related to teaching is with me" (Interviewee 2)

4.1 Active learning and competence

At this point, the participants were asked about their respective understandings of active learning and competencies in the context of higher education.

It is a consensus among the interviewees that active learning is fundamentally characterized by student protagonism, which was recorded in different but convergent ways among the interviewees.

"(...) effort that the student undertakes on their own initiative to achieve the defined objectives (Interviewee 1)."

Interviewee 3 understands active learning as a paradigm founded on student centrality, while also paying attention to the role of the teacher.

"(...) are those teaching strategies or methodologies that place more, that propose more autonomy for the student, which does not mean less agency on the part of the teacher, because for this autonomy to be effective on the part of the student, they need to be prepared for it, but I think the focus is always on this centrality of the student as the author and as responsible for the construction of their, co-responsible, in fact, for the construction of their learning" (Interviewee 3).

The relationship between active learning and the development of competencies in higher education “implies actions” (Interviewee 3).

“(…) the competencies are associated with what will enable the student to perform their role outside the university, in the labor market (...) knowing how to listen (...) personal relationships” (Interviewee 6).

“It is not enough to give a theoretical lecture on what collaborative work is for my students to effectively learn to work collaboratively. Or communicative ability. A lecture on the characteristics of good communication is not enough for students to effectively learn or develop this competence” (Interviewee 3).

Finally, there is an understanding that active learning in higher education would lead students to the construction of competencies for professional development.

“(…) active learning in higher education is a priority for promoting human development and (...) they are active in the sense that they mobilize not only knowledge but also other competencies that are essential for integral development (...) critical thinking, communication, creativity, dealing with conflicts, relating to others and oneself” (Interviewee 4).

From these fragments of the interviewees' reports, it is possible to perceive that active learning strategies favor the construction of competencies in students not only from a technical point of view but, above all, those transversal competencies that also prepare them for the labor market. Both among the interviewees and in the literature, there seems to be a consensus that such strategies lead to satisfactory educational and professional outcomes.

4.2 Active learning and institutional support/strategies

In this topic, the objective was to understand the interviewees' conceptions of active learning and the institutional aspects that favor it.

Although the strategic documents of the studied institutions mention active learning approaches, this fact does not guarantee the adoption of the method.

“I would say that we have guiding documents that are aligned with active methodologies. Often, the directors, most of the directors, are also aligned. Sometimes, from my reading, there is some difficulty between the coordinators and the teachers” (Interviewee 4).

When asked whether the institutions encourage active learning strategies, it stands out in this case that the institutions do not clearly encourage or do not encourage the adoption of active learning strategies for the professional practice of students.

“I think so, but very occasionally still (...) I don't think the institution does enough for these strategies and methodologies to effectively appear transversally in the different academic units and in the different educational offerings that the university has” (Interviewee 3).

“(…) although I am aware of specific actions by certain groups that try to do so, there is no institutional support” (Interviewee 7).

By 'specific,' the participants refer to initiatives by teachers and not to the existence of an institutional policy that encourages active learning strategies.

“(…) we are a relatively new office, and we work a lot with teachers who voluntarily want to work with us (...) so, there is not yet institutionalized a guide or a set of practices that are beneficial for teachers to propose in their classes” (Interviewee 5).

"Teachers do not receive any incentive to participate. Because they are not recognized in any way. In the pedagogical surveys, something in this sense is slowly starting to appear. So, institutionally, there is a very long way to go" (Interviewee 3).

"(...) the issue is always with the teacher, who has pedagogical autonomy (...)" (Interviewee 4).

The interviewees understand that active learning strategies are relevant to most subjects and content areas. However, the majority advocate for the coexistence of traditional teaching methods—characterized by lecture-based, teacher-centered approaches—and active learning strategies, which emphasize student agency. Particularly in the Brazilian context, and in light of the lack of institutional support, resistance stems from the fact that "people do not know what to do or how to do it."

"(...) The institution might need to encourage faculty more actively to become familiar with these new strategies (...) There are courses that perhaps do not yet fit into this model, but I would, at the very least, like to try at some point. However, in order to try, I would need support. (...) For instance, I am quite apprehensive about implementing a flipped classroom approach. (...) If I walk into the classroom and say, 'Everyone, let's begin our debate,' and they haven't read anything, then, for me, it was all for nothing." (Interviewee 9)

However, Interviewee 3 points out that merely offering training in isolation, so that faculty can engage with active learning strategies, is not sufficient. As stated, "it depends not only on interest, but also on the goodwill and availability of the instructors to take part in these initiatives. There is no institutional incentive for them to effectively participate in these training sessions".

The accounts clearly highlight the need for the institutionalization of active learning strategies or for institutional support so that such strategies may be adopted with the deliberate aim of enabling students to develop the competencies necessary for their professional growth. Furthermore, institutionalization would also entail the practice and professional development of faculty, so they can identify which strategy is most appropriate for each type of content.

4.3 Active learning and professional practice

In this section, interviewees were encouraged to list the characteristics they observe in the professional practice of students, as well as to reflect on how the development of these characteristics is, or is not, supported by active learning strategies in the institutions studied. At this point, it can be stated that there is a convergence among the institutions surveyed.

The interviewees listed the competencies they recognize in the professional profile of graduates from the institutions studied. There is a convergence of competencies between the two institutions. These include: critical thinking, ethics, social responsibility, autonomy, teamwork, communication, and technical competence.

Finally, when asked to describe how such competencies are fostered within the institutions where they work, the responses were also convergent.

"I would say that, in general, the institution does its best to develop this type of competency, particularly critical thinking. Because, quite often, many professors encourage discussion and prompt students to speak and try to express their opinions on certain topics." (Interviewee 5)

"(...) we have engaged in volunteer activities (...) numerous initiatives within the community." (Interviewee 1)

"I don't know if it's because they've been exposed to active strategies, but a variety of other activities contribute to this [stimulating competencies]: extension activities, junior companies, internships, considering this broader type of education." (Interviewee 7)

What can be inferred from the interviews at this point is that the institutions studied are able to identify characteristics and competencies that contribute to the professional development of students. However, it cannot be stated with certainty whether the development of these competencies is a result of the adoption of active learning strategies.

5 Conclusion

This ongoing research explores how, from an institutional perspective, active learning contributes to the development of competencies in the context of higher education at two institutions.

The results obtained from the data collection allow us to affirm the importance of active learning strategies for the professional practice of students. The interviewees unanimously recognize this teaching-learning method as relevant, and the scientific literature indicates an improvement in educational outcomes through the adoption of such strategies.

However, from an institutional perspective, there is no clear adoption of these active learning tools in either of the two institutions studied. While there are references to active learning in institutional strategic documents, there is no clear evidence of formal institutional support for encouraging such practices.

In both institutions, there are departments that discuss pedagogical practices, but this is not enough to encourage active learning. As the interviewees consistently state, the adoption of active learning tools, approaches, and strategies depends on the initiative of the instructor. Although there is no obstruction to adopting such practices, there is also no clear incentive. There is discourse! Persuasive discourse! But the effectiveness of such practices needs to go beyond words. The instructor engages in these practices because they believe in the method, not because the development of transversal competencies is a priority.

There is no doubt that technical practice is prioritized and taken seriously at the institutions. Technically, at both institutions, the student develops this competency. However, the job market also demands transversal competencies, which go beyond and complement the technical practice.

Knowledge is constructed in various environments, including the classroom. Knowledge is built by the teacher, the student, and the relationship between these agents, as well as their connection to the professional world and the world in which they are engaged. At times, traditional methods are not sufficient.

The answers to the questions guiding this research – what institutional initiatives promote competencies in the professional development of students and, in particular, how active learning contexts, in their various educational settings, contribute to the development of these competencies – are being constructed through listening to the agents who are institutionally involved in the selection of learning strategies.

The results demonstrate the need for the institutionalization of active learning strategies in the professional development of students. The interviewees highlight the necessity of institutionalization, recognize the challenges in dealing with these strategies, but also suggest possible measures for institutionalization, such as: "a coordinator capable of motivating, involving, and creating space" (Interviewee 4); fostering existing initiatives like pedagogical departments; encouraging (not necessarily financially) professors to adopt these strategies by rewarding them, for example, with points for career advancement, among other measures that

the research will further identify. In other words, the goal is to integrate active learning strategies into institutional guidelines, making them feasible practices for both teachers and students.

The connection between professional practice and active learning follows these sometimes innovative paths.

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Scenario-Based Competence Assessment for Developing Behavioral Competences in Engineering Education: A Systematic Literature Review

Rafael R. Pereira¹, Mariane C. de Souza², Bibiana P. da Silva², Fernanda A. P. Peres², Antonio D. Brasil², Diana Mesquita³

¹ School of Chemistry and Food, Federal University of Rio Grande. Rio Grande, Brazil.

² School of Engineering, Federal University of Rio Grande. Rio Grande, Brazil.

³ Universidade Católica Portuguesa, Faculty of Education and Psychology, Research Centre for Human Development, Portugal

Emails: rafaapereira78@gmail.com, marianecasseres@gmail.com, bibiana.ea@gmail.com, fernandaperes@furg.br, antoniobrasil@furg.br, dmesquita@ucp.pt

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Abstract

Competence assessment and development are constantly evolving, following methodological and technological advances. Scenario-based competency assessment as a tool to develop behavioral competencies has gained prominence in response of criticism of traditional assessment methods. Unlike conventional approaches, scenario-based assessment uses hypothetical situations based on real contexts, allowing participants to demonstrate their competencies in simulated environments that reflect everyday professional situations. The study aims to understand the state-of-the-art applicability of scenario-based behavioral competency assessment in engineering education. The researchers analyzed studies aligned with the central theme through a systematic review. The methodology followed the PRISMA guidelines, ensuring rigor in data screening, organization, and analysis. The results of this study show that, despite the intriguing and promising potential of scenario-based assessment, there is a significant gap between its practical application and its academic exploration in engineering. The analysis revealed a still limited mosaic of publications, suggesting that this approach, although recognized in other areas, such as medicine and education, remains largely unexplored in engineering education. This scenario highlights the need for further research and strategic planning to enable broader and more effective adoption of this methodology.

Keywords: Assessment. Competences. Scenarios. Systematic Review. Engineering Education.

1 Introduction

The competence assessment and development field are constantly evolving, reflecting changes in the methods and tools used (Wawak & Woźniak, 2020). Competency assessment emerged in response to the growing criticism of traditional tests, which were considered unrealistic assessment methods. As a result, there has been a decline in the confidence of tests as valid tools for measuring learning (McDowell, 1995). With the growing emphasis on competency-based learning and teaching, there has been an increasing demand for assessment methods to determine these skills effectively (Baartman et al., 2007).

Scenario planning is an assessment and learning approach used for over 50 years and has expanded over time. We can define scenarios as any activity that exemplifies specific situations or themes in the workplace (Carrol, 1999). Authors generally present these scenarios in the form of narratives, which can encompass a particular set of circumstances, a description of human behavior, an outline of events, a story of human endeavor, an incident in the workplace, or a human dilemma, on which the participant reflects to plan their actions.

This assessment method transcends the boundaries of different areas of knowledge, and its research has gained prominence in all countries. However, in the context of Engineering, this method is still relatively recent, especially when compared to areas such as Medicine and Education (Souza & Lima, 2020).

Given this scenario, the study aims to understand the state-of-the-art applicability of scenario-based behavioral competency assessment in engineering education. It seeks to answer the following research question: How can scenario-based competency assessment contribute to developing behavioral competencies, especially in engineering education? The researchers conducted a systematic literature review in the Scopus and Web of Science databases, following the protocol developed by Moher et al. (2009).

2 Theoretical Framework

The concept of "competence" continues to be widely discussed and interpreted differently in the organizational and occupational literature (Hijazeh, 2011; Sanghi, 2016). Although the concept was defined over three decades ago, its application in project management remains relevant for various purposes.

Several studies investigate aspects such as leadership development, cooperation, knowledge management, sponsor perceptions, and management in complex environments (Crawford, 2005; Kasvi, Vartiainen & Hailikari, 2003; Söderlund, Vaagaasar & Andersen, 2008; Turner & Müller, 2005; Geoghegan & Dulewicz, 2008; Müller & Turner, 2010; Gray et al., 2013; Suikki, Tromstedt & Haapasalo, 2006; Thomas & Mengel, 2008). These studies, often published in specialized journals, discuss the competencies that project managers must develop to achieve project objectives, emphasizing behavioral competencies.

Crawford (2005) proposed a tripartite classification of competencies: input, personal, and output. Input competencies refer to the knowledge and skills brought to the project, while output competencies are related to observable performance in the work environment. Personal competencies involve essential attributes that allow the individual to perform his/her role.

IPMA (2015) adopts a similar definition, describing competence as the practical application of knowledge, skills, and abilities to achieve desired results. Thus, a competent person has the necessary attributes to achieve the expected performance, as shown in Figure 1.

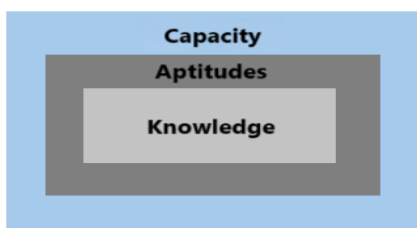


Figure 1. Representation of the Definition of the term Competence. Source: IPMA (2015)

According to IPMA (2015), the ten behavioral competencies of project management are: introspection and personal management, personal integrity and reliability, personal communication, relationships and commitment, leadership, teamwork, conflict and crisis management, engagement, negotiation, and results orientation.

The field of education has undergone substantial transformations, especially with the increasing adoption of competency-based approaches (Chappell et al., 2020; Griffith & Lim, 2014). The structure of assessment practices requires verifying whether the participant has the knowledge and what he or she can do with the knowledge acquired in real situations in the market environment (Mirza et al., 2023; Poth et al., 2020).

According to Marinho-Araújo and Rabelo (2015), assessment is a complex process that involves conceptions, beliefs, values, principles, theories, concepts, goals, desires, and trajectories. Developing the ability to identify, mobilize, manage, and use these sets of resources, together with knowledge, expertise, and other relevant characteristics, highlights an individual's competence.

In this context, one of the main challenges in the assessment process is to create activities and methods that encourage the practical application of skills. Ketele and Roegiers (2016) propose a classification of assessments into three distinct approaches. Instruments such as interviews and written tests are used when the assessment adopts the questionnaire approach. In the observation approach, rubrics and checklists are used. In document analysis, portfolios, reports, and self-assessment forms are used.

Scenario-based assessment is an approach in which hypothetical situations are created but grounded in authentic contexts to which individuals must respond. The tasks of this type of assessment and their items usually present a brief description of the situation, followed by questions or prompts designed to elicit behaviors or perceptions related to the construct under analysis. Scenario-based assessment thus offers a means of assessing individuals in meaningful and purposeful contexts, with tasks that reflect their experiences. This method is particularly effective in connecting informal but complex social activities, ensuring the collection of robust and reliable data on human behavior in real-world settings (Haynes et al., 2009).

Each assessment task is presented as a hypothetical situation, described orally to the participant, and based on everyday contexts. The strategy uses situations familiar to the respondents without requiring knowledge from formal educational experiences (Mutweleli et al. 2024).

3 Methodology

The researchers carried out a systematic literature review (SLR) using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, as proposed by Moher et al. (2009). The study selection process comprised four distinct phases — identification, screening, eligibility, and inclusion — as depicted in Figure 2. The PRISMA framework aimed to optimize the scope of the search and ensure methodological rigor in selecting relevant studies for the review.

The researchers collected data in December 2024 from the Scopus and Web of Science databases. The search strategy employed the following combination of terms: ("Skills Assessment*" OR "Competences Assessment*" OR "Competences Assessment Methods*" OR "Assessment of Engineering Competences*" OR "Competence Evaluation Model*").

Table 1 presents the detailed inclusion and exclusion criteria for study selection.

- Studies published in journals.

- Relevant to the areas of interest: Education, Engineering and Business, Management and Accounting.

- Classified as "Article" or "Review" document types.

- Written in English.

The information was recorded in an electronic spreadsheet containing the author(s), year, location, objectives, methodology, and competence assessment criteria. Finally, the compiled data were subjected to a bibliometric analysis. This analysis aimed to identify patterns in scientific production and map the knowledge landscape, including authors and journals of greatest relevance to the topic investigated (Alfonso et al. 2021; Dutra et al., 2015).

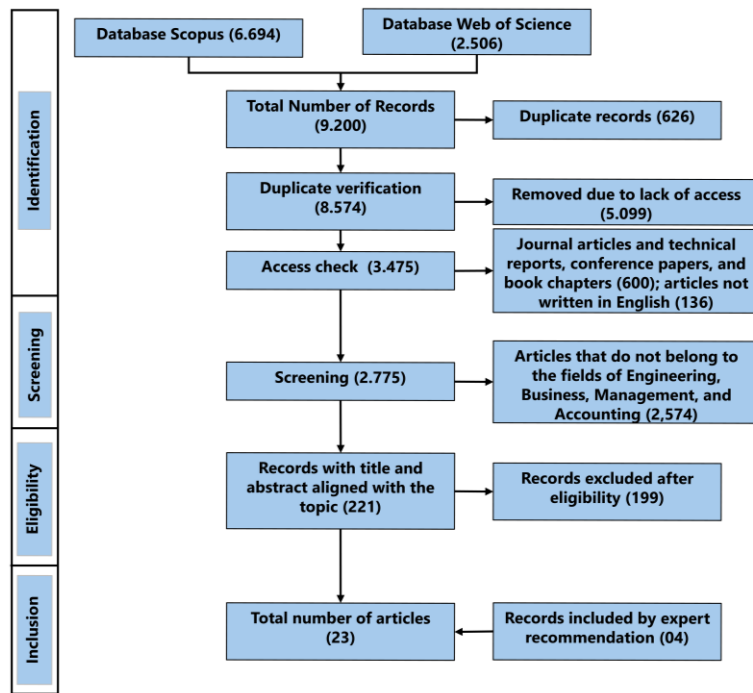


Figure 2. PRISMA method

4 Results and Discussion

The literature review selected 23 articles addressing different competence assessment methods. The data revealed a gap in the use of the scenario-based approach indicating that despite its potential, this methodology is still in its early stages in the field of engineering. Table 1 presents the main assessment methods identified in the studies.

Table 1. Competence assessment methods

Author(s)	Field of Application	Competence Assessment Method
Liu (2024)	Education	Questionnaire
González-Fernández et al., (2024)	Education	
Chouhan (2022)	Engineering and Business	
Hirschprung & Kordova., (2021)	Education	
Köuts-Klemm (2019)	Education	
Carr, Bowe & Ní Fhloinn (2013)	Engineering and Business	
Taylor et al., (2012)	Education	
Baartman et al., (2011)	Education	Scenarios
Davis et al., (2023)	Education and Engineering	
(2023)	Engineering and Business	
Souza et al., (2022a)	Education and Engineering	
Tinoco et al., (2023)	Engineering and Business	Self-assessment
Hero, Pitkärjärvi & Matinheikki-Kokko (2021)	Education	
Bohloul et al., (2017)	Engineering and Business	
Achcaoucaou et al., (2014)	Education	Headings
Adorni et al., (2023)	Education	
Souza et al., (2022b)	Education and Engineering	
Succi & Wieandt., (2019)	Management and Accounting	Simulation/Games
Altomari, Altomari, & Iazzolino (2023)	Management and Accounting	
Politis et al., (2023)	Education	Observational
Gómez, Sabater-Mir & Sierra (2022)	Education	Peer review
Tang, Tsai & Huang (2020)	Education	Skill Hierarchy
Lin et al. (2018)	Education and Engineering	Based on Continuous Data

The analyzed articles highlight a range of skill assessment approaches, from traditional methods (such as questionnaires, interviews, and rubrics) to interactive ones, such as games and simulations.

The most commonly used method for assessing behavioral competencies in the literature is the questionnaire-based assessment, accounting for 35% of the studies. The Competency Assessment, through a **Questionnaire**, assesses professional competencies, including professional identity, planning, communication, methodology, innovation, collaboration, and meta-evaluation, essential for improving learning. The authors Liu (2024), González-Fernández et al. (2024), Chouhan (2022), Hirschprung and Kordova (2021), Köuts-Klemm (2019), Carr, Bowe and Ní Fhloinn., (2013), Taylor et al. (2012) and Baartman et al. (2011) actively use this form of assessment, applying it in various contexts such as universities and industries.

Scenario-based assessment represented 17% of the articles included in the research. The studies by Davis et al. (2023), Souza, Lima, and Mesquita., (2023), Tinoco et al. (2023), and Souza et al. (2022a) presented scenario-based assessment. This method exposes university students to unstructured problems that simulate situations aligned with professional practice. Participants can identify students' critical thinking and problem-solving skills by analyzing and answering questions related to the scenario presented. During university selection processes, educators and employers can apply the scenario-based assessment method to students and the industry.

Self-assessment, representing 13% of the articles, allows participants to reflect on their skills and knowledge. This method allows the assessment of seven individual skills related to innovation: personal characteristics, implementation and planning skills, project management, creative thinking, social skills, future orientation, and disciplinary knowledge (Hero & Lindfors, 2021). The research by Hero, Pitkälä & Matinheikki-Kokko., (2021), Bohlouli et al. (2017), and Achcaoucaou et al. (2014) stands out in this method.

Rubric-based assessment accounts for 13% of the articles and allows the systematization of the evaluation process, establishing the relationship between skills and observable behaviors. This method presents an approach to model learning skills, assisting evaluators in analyzing student development (Adorni et al., (2023), Souza et al., (2022b), and Succi & Wieandt., (2019).

The other assessment methods represented 4% of the studies and consisted of simulations/games, observational, peer assessment, skills hierarchy, and assessment based on continuous data. In the study by Altomari, Altomari & Iazzolino (2023), **Simulation** was the assessment method that employed event sequence analysis techniques, comprising the organization and recording of the assessed person's actions and decisions. This method allowed the analysis of five behavioral competencies: problem-solving, teamwork, time management, decision-making, and communication. This method was developed at a university to identify and assess the essential competencies required by the job market.

The method characterized as **Observational Assessment** is based on the direct observation of individuals' behavior during social interactions, using previously defined criteria to analyze their conversational skills. This method was applied in an intervention context with young autistic adults on a virtual platform through training sessions held both in person and virtually, aiming to develop and improve these skills (Politis et al., 2023).

Peer Assessment allows the assessment of skills such as critical thinking, writing skills, self-assessment, and collaboration, highlighting its relevance in educational environments, especially in online courses (Gómez et al., 2022).

Ability Hierarchy is an innovative mathematics assessment system used in elementary schools. It analyzes learning difficulties by organizing skills into progressive levels, ensuring that participants master basic concepts before advancing to more complex topics, such as whole numbers, fractions, and area calculations (Tang et al., 2020).

The study by Lin et al. (2018) describes **Continuous Data-Based Assessment**, an approach applied to software engineering that measures technical and interpersonal skills through behavior analysis in authentic tasks. By integrating formative assessment practices with quantitative metrics, this method gathers and analyzes student activities within an agile development environment to evaluate their performance.

The systematic review findings highlight that most studies use the most traditional assessment method through the application of questionnaires, followed by the scenario method. However, there is a need for further studies on competency assessment, particularly about scenario modeling as a methodological tool. Although widely adopted in areas such as medicine and education, the application of competency assessment in engineering remains scarce, representing an opportunity for research and development. Studies such as those by Margalho (2022) and Souza & Lima (2020) highlight this gap by showing that most publications on scenarios in competency assessment focus on areas such as health and public management. The results indicate that the engineering field has not yet adopted this methodology significantly in its assessment practices.

In this sense, the results corroborate the scarcity of research on the topic and indicate the potential of scenarios as a promising methodological approach for assessing competencies. This approach enables a more dynamic, interactive, and contextualized environment, favoring the measurement of participants' competencies (Souza, Lima, & Mesquita, 2023).

In the academic context, higher education institutions have intensified their efforts to reach the business sector. This movement is a result of the growing market demand that has stimulated the transformation of classrooms, ensuring that students develop not only solid theoretical knowledge in their areas of study but also behavioral skills that are essential for good professional performance and aligned with contemporary demands (Castaño Urueña et al., 2024; Ogunrinde, 2022). The literature shows a series of limitations related to the traditional teaching model, contributing to students' inability to solve problems, work in teams, and communicate (Hansen & Luxhøj, 1995; Souza, Lima & Mesquita, 2019).

Thus, the scenario-based competency assessment method can potentially assess behavioral competencies more realistically and aligned with the professional demands of the job market. Scenario-based assessment is believed to allow the participants to mobilize their competencies, express their reasoning more openly, and use creativity in a visual, dynamic, practical, and interactive process (Tinoco et al., 2023).

5 Conclusion

This study examined the application of scenario-based competence assessment in engineering education, highlighting the lack of research exploring this approach in this field. The systematic review showed that, although there are several assessment methods in the literature, the use of scenarios to measure competencies is still little explored in engineering, in contrast to its consolidation in areas such as medicine.

The results indicate that scenario-based assessment can be a promising alternative to traditional methods. It enables the assessment of technical and behavioral skills and fosters critical thinking and decision-making in contexts similar to professional reality. This approach stimulates problem-solving, teamwork, and adaptation to complex situations in engineering education, promoting more dynamic and contextualized learning.

Thus, scenario-based assessment contributes to developing behavioral skills by exposing students to challenges that simulate actual professional conditions. However, empirical studies are still needed to validate its effectiveness in engineering education.

In light of this, it is recommended that structured models be developed and comparative studies conducted alongside conventional assessment methods to evaluate their impact on student education. By highlighting

the potential of this methodology, this study reinforces the importance of deepening both the theoretical foundation and empirical investigations, encouraging new research that expands its application in engineering.

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Student Assessment under Complex Thinking: Driving gamified self-made Students' summative assessment (gSSA)

Andre Fernando Uébe-Mansur^{1,2}, Anabela C. Alves³

¹ Fluminense Federal Institute. Campos, Brazil.

² Norte Fluminense State University, Campos, Brazil.

³ ALGORITMI/LASI Centre, Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal

Email: andreuebe@iff.edu.br, anabela@dps.uminho.pt

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Abstract

This study presents a method for creating summative assessments by the students, under the Complex Thinking approach. As an innovation, the method requires students to propose their summative assessment questions, which is made possible through the gamification learning strategy. A case study describes the aspects of the experiment, the method development stages, and the results obtained. The experiment development occurred during the first semester in a theoretical discipline called "Organisational Administration", where the four functions of Administration are studied in the bachelor's degree in Information Systems at the Instituto Federal Fluminense. In the traditional learning methods, expositive classes are the usual approach for theoretical disciplines like "Organisational Administration." In this case, the flipped classroom and problem-based learning were adopted as an active learning approach and diagnostic and formative assessments. Then, the summative assessment described in this study was not more important than the other assessments, as usually happens with traditional learning methods. The findings suggest that the technique was highly successful in fostering playful student engagement. Additionally, it alleviated the teacher's workload by decentralising the summative assessment elaboration. Finally, the experiment shows how it is possible to promote students' assessment according to the Complex Thinking premises.

Keywords: Summative Assessment; Active Learning; Gamification.

1 Introduction

Student assessment is a challenge for teachers and educational institutions. This challenge is scaffolded by some driven questions, such as: How could students be assessed to verify their knowledge? What would be the right way to assess the students? In addition, more in-depth, what is the real purpose of student assessment in a Complex (Morin, 2001) context?

Teachers, institutions, and students are increasingly concerned about the limitations of traditional expositive learning methods (TELM) in meeting the professional and academic demands of the 21st century. However, recent research has brought excellent results related to adopting active learning approaches (ALA), such as flipped classrooms, gamification, project-based learning, problem-based learning, and more (Alves & van-Hattum-Janssen, 2022; Rieg et al. 2022; Lima et al. 2024).

In the TELM, student assessment is not considered a challenge by the teachers and institutions due to the worry of applying one-off summative content assessments in most cases with objective and discursive questions. In this case, the major concern is to prepare questions that are difficult enough to prevent students from correctly answering the question without a minimum of reflection.

However, the fact is that, like the TELM, the one-off summative content assessments (OOSCA) cartesianiously verify a very small aspect of student knowledge: their capability to memorise or reflect on some concept. Doing this, exist an overvaluation of technical competencies to the detriment of their social abilities and professional skills, which are ignored in this type of assessment (Kleim, 2000; Felder & Silverman, 1988).

Since teachers have adopted ALA, the dimension of students' assessment has become more complex because the assessment cannot be limited to a content approach as adopted in the TELM. For the ALA, OOSCA is only one of the different ways to assess the students, not having the same importance attributed to it in the TELM (Fernandes et al., 2021).

Despite OOSCA having less importance for ALA than TELM, it does not mean that OOSCA is unimportant. However, a simple adoption of OOSCA for ALA (as is being adopted in TELM) seems to be a poor way to take the potentialities of ALA. For example, OOSCA/TELM only consider students as passive characters of the learning process because they only answer the objective or discursive questions made by the teacher.

In the context of ALA, where summative assessment is only a part of a range of assessment ways like self-assessment, peer assessment, and external assessment, this paper proposes a gamified self-made students' summative assessment (gSSA). In this, the students have become the protagonist, developing their summative assessment through gamification. This proposal was applied in a case study: a cohort from the discipline "Organisational Administration".

This paper is structured in five sections. This introduction is followed by Section 2, which contains the concepts of assessment and its types, as well as the concept of gamification as a learning approach. Section 3 brings the gSSA for summative assessment development in the context of ALA. In Section 4, the results are presented. In Section 5, a discussion is undertaken, followed by the conclusion in Section 6.

2 Study Context

This section brings the theoretical concepts related to the present research: assessment strategies and gamification concepts.

2.1 Student assessment strategies under Complex Thinking

Assessment is inherent to a learning process that can be considered as a feedback message about how students should fit into the learning (Uebe-Mansur & Alves, 2018). From our first breath as a learning person, the assessment is there, allowing us to grow and become professionals who will continuously be trained and assessed in the workplace (Uebe-Mansur & Alves, 2020). However, independently of the context, it is always complex and, most of the time, students feel unfairness, frustration, and demotivation among others. Involving the assessed persons (students, trainees) could reduce these sentiments.

Complexity or Complex Thinking is a way of thinking about life and its things that emphasizes the interconnectedness in contrast to the fragmenting thought of Cartesians proposed by the philosopher Rene Descartes. Complex Thinking seeks to stitch together that was fragmented by Cartesian reductionist thinking, seeing the complexity of real-world phenomena, rejecting simplistic reductionist approaches. Instead advocating for a holistic understanding that considers multiple perspectives, interactions, and levels of analysis within a system. Essentially, it is a way of thinking that acknowledges the intricate nature of reality and avoids oversimplification by integrating diverse factors and considering the dynamic relationships between them (Morin, 2007; Morin and Mortuori, 2008).

At the same time, this could be reduced by applying different assessment strategies as they assume different roles. These assessment roles are grouped, mainly, into two categories: 1) summative assessment and 2) formative assessment (Hadji, 1994). According to Fernandes et al. (2021), the summative assessment goal is to certify, compare and select, while formative assessment aims to monitor, guide, improve, support and regulate student learning. These assessment roles are also related to different types of assessment methods: traditional methods, which include tests and examinations, related to summative assessment, and alternative or student-

centred methods, for example, portfolios, simulations, project-based learning, and flipped classrooms among others.

In addition, Earl and Katz (2006) categorise these assessment roles according to their purpose of assessment, distinguishing assessment practices from three different perspectives: *assessment of learning*, *assessment for learning*, and *assessment as learning*. The first is related, mostly, to summative assessment and the latter two on formative assessment practices.

Succinctly, the three assessment practices can be described as: 1) *assessment of learning* usually takes place at the end of a task, unit of work, etc. and its purpose is mainly summative; 2) *assessment for learning* puts the shift from summative to formative assessment and assessment happens during the learning, often more than once, rather than at the end. It is an interactive process, and 3) *assessment as learning* is understood as a process where teachers construct and use assessments to allow students to think about and monitor their learning and develop internal feedback or self-monitoring mechanisms to validate and question their judgements (Fernandes et al., 2021).

In this process of assessment, it is also important to remember that all students have different learning styles (Felder & Silverman, 1988) and a “one-size-fits-all” solution will always exclude students from a fair and personalised assessment solution. To avoid this, teachers must use as many different assessment methods as possible, also attending to the balance of teachers and students' workload (Alves et al., 2021; Alves & Uebe-Mansur, 2018).

As Cartesian and fragmented thinking is still predominant in academic graduation environments, diagnostic and formative assessments are usually ignored by many teachers, who emphasise spot summative assessments considering them a full and effective way to verify a student's apprentice. This assessment approach is in the opposite direction of what Morin (2003) and Kleim (2000) claim about the urge to think in an academic environment more complex, where interdisciplinary in the subjects and transdisciplinary related to humanity themes are urgent in the 21st-century school model. Finding ways to re-think the learning and assessment model, considering the complexity of human beings and not only the fragmented and Cartesian point of view that considers isolated themes and assessment moments is crucial.

2.2 Gamification

Gamification is not a serious game like many examples provided in the literature, namely, (Alves, 2018; Hotta et al., 2024; Sousa et al., 2014; Witeck & Alves, 2020; Zhonggen, 2019) but it uses game elements and mechanics in non-game contexts (Khaldi et al., 2023; Liu et al., 2023). It makes use of goals, levels, stages progression, challenges, status, leader board, and feedback among others, as a way to make the most attractive and challenging activities.

Zichermann and Linder (2013) defined the term gamification as “using game-based mechanics, aesthetics and game thinking to engage people, motivate action, promote learning and solve problems.”. They added that the goal is to create a system in which learners, players, consumers, and employees engage in an abstract challenge, defined by rules, interactivity, and feedback that results in a quantifiable outcome ideally eliciting an emotional reaction. And, among describing elements of this definition, they described the “game-based element” which means something where people want to invest their brain share, time, and energy.

According to the Liu et al. (2023) study, gamification group participants were more likely to engage in proactive behaviours such as contributing and asking more questions in class, interacting with their peers, arriving early to class, spending more time studying and being more proactive with mentorship. In addition, they concluded

that a learning environment enriched with game design elements specifically evokes curiosity, improving learning outcomes for learners.

According to Kapp (2012), gamification uses innovations from game design, loyalty programs, and behavioural economics. This same author said that gamification presents the best tools humanity has ever invented to create and sustain engagement in people. He also said that gamification is a proven approach using breakthroughs in technology and design to vastly improve the world, as we know it - and deliver the organisational success you desire. This is a practice that has been gaining attention in several sectors, for example, education, marketing, economics, medicine and the military sector (Chapman & Rich, 2018; Costa et al., 2021; Kapp, 2012; Markopoulos et al., 2015; Zichermann & Linder, 2013). Zichermann and Linder (2013) referred to a survey where 55% of people would be interested in working for a company offering games as a way to increase productivity.

Although the gamification benefits are well known, being presented in the previous paragraphs, some design and application difficulties appear, namely, choosing the right combination of game elements that remains a challenge for gamification designers and practitioners due to the lack of proven design approaches (Khaldi et al., 2023). The same author said there is no "one-size-fits-all" approach that works regardless of the gamification context.

3 The gamified self-made students' summative assessment (gSSA)

The gamified self-made students' summative assessment (gSSA) results from a case study that occurred during the first semester of 2024 with all of the 20 students enrolled in the Business Administration discipline from the Bachelor of System Information at Fluminense Federal Institute.

The discipline of Business Administration brings theoretical knowledge related to the four business functions: planning, organisation, driving, and controlling. During the classes, the teacher guided the students to previously watch videos concerning the content of the classes and comment on related issues or interesting aspects, according to the Flipped Classroom (FC) and Problem-based Learning (PBL) pedagogical approach. The teacher got the videos on YouTube Playlist as available at: <https://youtu.be/ykmS6V1Wmrl?si=EvlapJbfpdlABZV1>. The general aspects related to the FC and PBL are not the main focus of this paper, only the gSSA..

The proposition of FC and formative assessments (FA) occurred innovatively for this kind of theoretical discipline. For this reason, the summative assessment does not have the same importance usually considered in traditional expository learning methods (TELM), being one more among other assessments for the discipline. Related to the discipline grades, the range goes from 0 to 10, being six points as the average to be approved.

On the first day of class, the discipline teacher informed the students about gSSA, explaining the general idea and deciding the rules together with the students. From this discussion, the students decided on these general rules:

- a) four teams with five members each;
- b) four objective questions for each team, totalling 16 questions at all;
- c) each round is driven by a team that asks four questions to the opponent teams;
- d) each team needs to answer 12 questions (equivalent to three rounds with four questions);
- e) each right question is equivalent to one point;
- f) as each team can obtain 12 points in total and the maximum grade is 10 (according to the syllabus), each team can make two incorrect answers, and yet obtain the maximum grade;
- g) each question has four possible answers, being one of them correct;
- h) set time question answering is four minutes (Kahoot's time limit);

- i) The source of data for the questions development is the YouTube playlist, the available eBook, and video comments made by cohorts on the videos from the YouTube playlist;
- j) only one player will represent the entire team.

Further to the one point by the right question e), Kahoot can be set to classify the teams in each round according to their agility to the correct answer. This option is not mandatory but is interesting as a tiebreaker criterion.

The rule j) concerns how questions are answered and team members' participation in each round and considers two possibilities. In the first possibility, only one team member represents the whole team in each round from a consensus to the right answer. The advantage is the process simplification since each question would have three answers (one for each group). The disadvantage is that members lose the opportunity to disagree with the rest of the team. The second possibility is each round could potentially involve all team members submitting individual answers. The advantage is the independence of each member to answer the question without the need to vote or agree with a general team consensus. The disadvantage is that the process became more difficult to drive because each team member would be computed separately.

Further, the general rules above were defined together with the students, the rules below were compulsory and dealt with some specific aspects of the gSSA. To encourage team members to study and create more thoughtful questions, the following rule was implemented:

- k) the opposing team has the opportunity to challenge any questions. If the opposing team successfully identifies an error in the question, they are awarded one point without having to provide an answer. However, if they are incorrect in their challenge, they lose one point.

To avoid teams cheating (for instance, sharing the questions among them in a way that all teams obtain the maximum grade by the previous knowledge of the opponent's correct answer), the following rule was established:

- l) if the team that answered the question incorrectly does not get the correct answer, the point for that question is awarded to the team that wrote the question.

The institution mandates that teachers assign an Individual Global Score (IGS) between 0 and 10 to each student. Students must achieve a minimum score of 6 to pass the syllabus without additional assessment. To meet this requirement, the teacher and students agreed on the following grading system: 60% of the final grade will be based on the average score of weekly tasks completed throughout the semester, and 40% will be based on the team score obtained from the gSSA.

The 40% team score, decided between the teacher and students, was as follows: the first-place team members received 10 points, second place received 8 points, third place received 6 points, and all other teams received 5 points. Figure 1 illustrates the IGS composition:

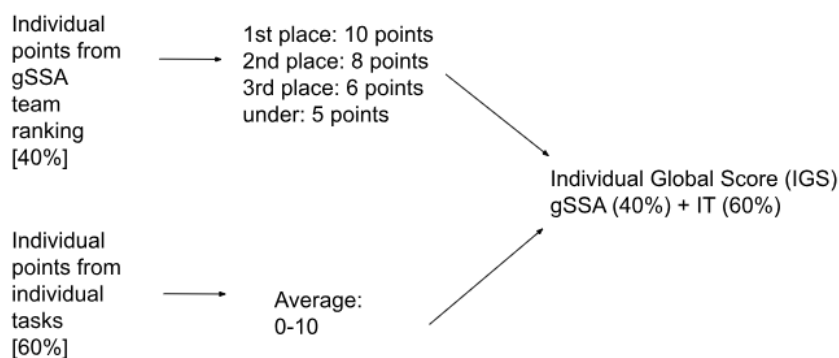


Figure 1. Individual Global Score composition.

4 Result Analysis

Despite the possibility of running the rounds manually analogously, the Kahoot app was the choice for running the rounds. According to *What Is Kahoot! | How to Play Kahoot!*, the app " (...) is a game-based learning platform that makes it easy to create, share and play learning games or trivia quizzes in minutes".

The advantage of the choice comes from Kahoot's feature that automatically bonus the faster player to correctly answer a question, eliminating the need for a stopwatch. The faster player bonus to correctly answer a question is not a mandatory rule by Kahoot, but promotes a sense of urgency among the teams and increases the player's capability to assert and correct thinking under stress, as also provides a qualitative aspect further the quantitative, obtained from correct answers.

The benefit of using "Kahoot!" is its automatic bonus feature, which rewards the fastest player to answer correctly. This eliminates the need for a stopwatch and promotes a sense of urgency among teams, enhancing players' ability to think quickly and accurately under pressure. Additionally, it adds a qualitative measure to the quantitative one based on correct answers. Although not mandatory, this feature encourages strategic thinking and improves overall performance.

A free public Kahoot account has some limitations, like a limit of 50 players in the same game and a limit of 120 characters. The player limit was not a problem due to the rule j). The character limit forced the students to develop their synthesis ability.

From these limitations, the gSSA explored in this paper consisted of four rounds (one for each team) with four questions per team (according to the rules a) to l), as followed by the team names:

- Team 1: *Seu Potencial* (SP);
- Team 2: SGC;
- Team 3: e-book;
- Team 4: VAPE.

At each round, a team proposes four questions (4 minutes/for each one), and the three others answer them, totalling four questions per round (16 minutes/total). As each team needs to participate in three rounds (total of team - 1), each team will have 12 questions to answer at the final of the three rounds. The estimated time for the four rounds is approximately one hour. Including the interval between the rounds for the teams to set up their games, the estimated time is approximately 1 hour and a half. Figure 2 shows the kind of question developed by a team among others.

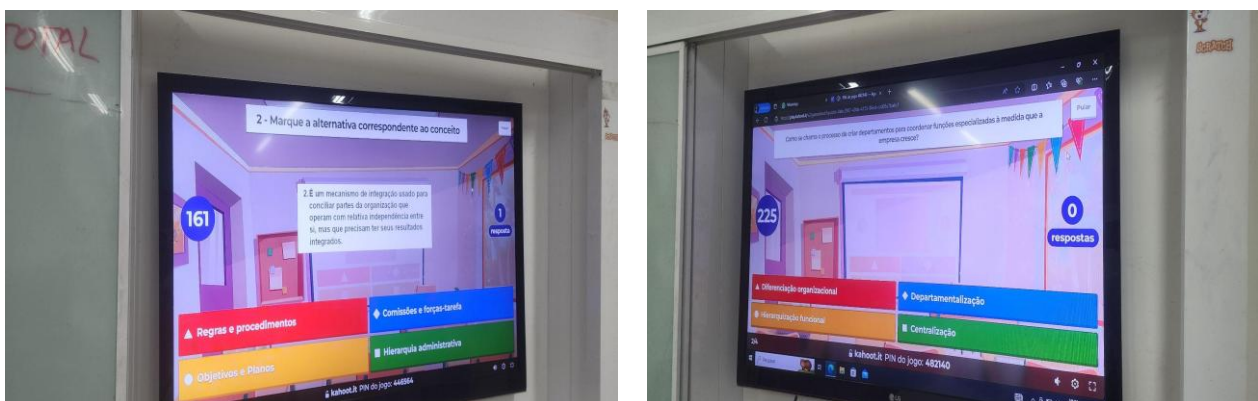


Figure 2: Examples of teams' questions on the Kahoot app

Figure 3 shows how the results for each round were calculated on a whiteboard. The researcher's choice to present the results as an image instead of a table, to show that it is possible to compute the results in learning environments where digital technology is not present.

The table's columns represent the four-question round driven by each team. The rows represent one of the four questions to the team's opponents. Each cell contains the Kahoot score for each team according to their agility to the correct answer, as also the indication if the questions were answered correctly (✓) or incorrectly (✗). If Kahoot is not used or this Kahoot feature is not set, only rule e) is considered. The last column contains the team classification according to Kahoot's fast-correct answer feature. The last row has the team's number of correct answers by round and the total number of correct answers according to the rule e).

EQUIPE	SGC	SGC	ebook	Vape	TOTAL
QUESTÃO	POTENCIAL				
1	Vape 847 V EBOOK 755 V SGC 710 V	SP-986 V Vape-851 V EBOOK-0 X	SGC-921 V SP-883 V Vape-859 V	SP-994 V SGC-977 V EBOOK-0 X	
2	Vape 1788 V EBOOK 1621 V SGC 1577 V	SP-1922 V Vape-851 X EBOOK-0 X	SGC-1869 V SP-1823 V Vape-1811 V	SP-1968 V SGC-1941 V EBOOK-965 V	
3	X	SP-2682 V Vape-1704 V EBOOK-896 V	Vape-2793 V SGC-2792 V SP-2721 V	SGC-2891 V SP-1968 V EBOOK-1793 V	
4	Vape 1788 X EBOOK 1621 X SGC 1577 X	SP-3580 V Vape-2516 V EBOOK-1846 V	Vape-3773 V SGC-3729 V SP-2721 X	EBOOK-2612 V SP-2942 V SGC-3856 V	Vape-8077 (3) SP-9248 (1) EBOOK-6084 (4) SGC-9162 (2)
PONTOS (ACERTOS)	Vape - 3 EBOOK - 3 SGC - 3 SP - 1	SP - 4 Vape - 3 EBOOK - 2	Vape - 4 SGC - 4 SP - 3	EBOOK - 3 SP - 4 SGC - 4	Vape - 10 SP - 12 SGC - 11 EBOOK - 8

Figure 3: Teams results in the whiteboard from gSSA

The opponent teams decided that "SP" team would lose their 3rd round opportunity (Figure 3, second column, fourth row) because their question violated the previously established rules for questions, proposition. The Table 1 shows the final results for Individual points from gSSA team ranking (according to the Figure 1).

Table 1: Teams' metrics

Team	Ranking	Hits (Kahoot) / efficacy	Score (Kahoot)	Grade (gSSA)
SP	1	12 / 100%	9248	10
SGC	2	11 / 92%	9162	8
Vape	3	10 / 83%	8077	6
E-book	4	8 / 67%	6048	5

Despite a summative assessment, students were very involved, and it was funny, as usual in the game competitions. The results presented in Table 1 shows the students in their majority acquired and understood the class content due in a scenario where gSSA would be the only assessment method, $\frac{3}{4}$ (75%) of the students achieved a minimum grade of 6 to pass the syllabus without recovery class test.

During the experiment, the students were actively engaged in the learning process, as they were required to create questions in a peer-assessment style format, which went beyond the traditional method of memorising content for a written test. This allowed them to evaluate their understanding of the material. Additionally, they completed two self-assessment surveys regarding their learning perception. The method lessened the teacher's workload by decentralising the creation of the summative assessment. This was achieved by having the students develop and censor the assessment's questions by themselves (as the penalty for the "SP" team).

The experiment described in this paper fostered an assessment complex environment, as evidenced by five aspects of Complex Thinking (Uébe-Mansur, 2011; Morin, 2007). These aspects are: a) Hologrammatic: Students were not only responsible for passively answering a survey, but for actively creating it; b) Recursivity: Some students independently developed innovative solutions without prior prompting; c) Reintroduction: Students learned from both their successes and mistakes, not only while playing the game but also during its development; d) Dialogy: Dichotomous aspects like assessment and fun were integrated; e) Systemic View: A holistic perspective of the process and subjects was formed through rules agreed upon by participants. These aspects were also evidenced in other related pedagogical experiences, namely Alves & Soares (2020); Soares & Alves (2021) and Hotta et al. (2024).

5 Conclusion

This paper presented a summative assessment developed by the students, under the Complex Thinking approach. By doing this, students become responsible for their own learning and assessment, developed innovative solutions, learning from their own mistakes, they had fun and were involved in the process. This summative assessment was only one part of the teaching process, which adopted interactive and engaging methods to explore theoretical concepts with students. Due to space constraints, other aspects of this experience, such as the learning methodology and formative assessments, it will be presented in future work.

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Active Methodologies in Teaching Economic engineering – A Systematic Literature Review

Ana Caroline Domingos Dias Moraes¹, Bibiana Porto da Silva², Mariane Cásseres de Souza^{2,3} Ana Carolina Prado¹, Bianca Fornagier Moraes², Vitor Camara Rebelo²

¹ School of Chemistry and Food, Federal University of Rio Grande. Rio Grande. Brazil.

² School of Engineering, Federal University of Rio Grande. Rio Grande. Brazil.

³ Department of Production and Systems, Algoritmi Centre, School of Engineering, University of Minho, Guimarães, Portugal

Email: carolineedias.13@gmail.com, marianecasseres@gmail.com, bibiana.ea@gmail.com, pradoanacarolinafurg@gmail.com, biancafornagier@gmail.com, rebelovitor9@gmail.com

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Abstract

Active methodologies, in educational contexts, are pedagogical approaches that assist the learning process, promoting the understanding and engagement of participants. Educators already use these methodologies in educational contexts; however, their application in STEM areas (Science, Technology, Engineering, and Mathematics) remains limited compared to other areas of knowledge. In Engineering, specifically in economics, teaching becomes challenging since some concepts are abstract, making understanding difficult and reducing student engagement. In this sense, the study aims to identify the most common active methodologies in engineering courses, focusing on economic engineering. The method was a Systematic Literature Review (SLR) conducted in the Scopus and Web of Science databases without time restrictions. Using the search terms "Active Learning", "Flipped Classroom", "Gamification", "Learning Strategy", "Problem-Based Learning", "Project-Based Learning", "Engineering", "Economic", applied to the title, abstract and keywords. In this review, 1,281 articles were identified, with the inclusion criteria of presenting the implementation of active methodologies in economic engineering or economics disciplines in engineering. Finally, the study selected twenty (20) articles for analysis. As a result, the study identified four (4) principal active methodologies used in engineering courses: PBL (Problem-Based Learning or Project-Based Learning), Gamification, Flipped Classroom, and Simulation. In economic engineering, 11 articles were identified that addressed the use of active methodologies, distributed as follows: simulation (1), gamification (3), flipped classroom (3), and PBL (5), the latter being the most used. Finally, the results show that PBL presented a high approval rate and efficiency among students, positively impacting their understanding and resolution skills of the proposed content. Therefore, we conclude that PBL is a promising methodology for teaching economic engineering and promoting greater engagement and learning. However, there is still a significant gap in studies that explore its application, highlighting the need to expand research in this area.

Keywords: Active Methodologies. PBL. Engineering Education. Literature Review.

1 Introduction

Engineering education has faced significant challenges in meeting the demands of a rapidly changing world. For many years, traditional teaching methods positioned the teacher as an authority figure, with students rigidly following his teachings, leaving no room for developing critical thinking. (Nagai & Izeki, 2013). However, educational institutions have increasingly sought innovative strategies to improve the learning process, making it more dynamic and efficient (Marin et al., 2010). The COVID-19 pandemic has intensified this need since the restrictions imposed by social distancing have led to the partial replacement of traditional teaching with remote and technologically mediated approaches. In this context, active methodologies are among the solutions found to ensure student engagement and provide more meaningful learning (Moreno & Rinaldi, 2021).

In STEM areas (Science, Technology, Engineering, and Mathematics), the content's complexity further accentuates the learning challenges, often resulting in lower-than-expected approval rates, as seen in economic engineering (Saccaro et al., 2019). This discipline requires students to develop broader and more

active thinking to understand the financial impacts of technical decisions, analyze economic scenarios, and apply feasibility concepts in real engineering contexts (Alfonso, 2021; Flemming, 2017; Zoghi, 2015).

The ability to perform economic analysis is an important skill for economic engineering. However, the methods and techniques involved in this process require the application of several economic and financial indicators in addition to the preparation of graphs, which can result in difficulty in retaining the information necessary to support decision-making (Dym et al., 2005). To overcome this challenge and favor the assimilation of knowledge, improving students' academic performance, Johnson & Johnson (2014) it has been demonstrated that the use of active methodologies, such as PBL (Problem-Based Learning or Project-Based Learning), flipped classroom, among others, can be defined as an effective strategy.

Despite the relevance of active methodologies in engineering education, including economic engineering, there are still knowledge gaps regarding the most widely used active methodologies in the academic context. Given this scenario, this study seeks to answer the following research questions: Which active methodologies do engineering courses most widely use? Moreover, which of these methodologies does the economic engineering discipline most widely use? To answer these questions, we conducted a Systematic Literature Review in the Scopus and Web of Science databases, following the protocol developed by Moher et al. (2009). In addition, we analyzed the bibliographic portfolio (BP) to identify the most widely used active methodologies and discuss their effectiveness and relevance in economic engineering.

2 Background

Active methodologies in educational contexts are pedagogical methods that aim to actively involve students in their learning process, developing skills for decision-making and problem-solving (Freeman et al., 2014; Olivieri & Zampin, 2024). In these methodologies, the teacher stops acting as the transmitter of knowledge and becomes the mediator or advisor, encouraging students to be autonomous, flexible, and think critically (Gallo et al., 2024; Moraes & Galiuzzi, 2020)

In this context, learning ceases to follow traditional patterns and begins to value student participation, incorporating experiences in scientific initiation and the job market (Freeman et al., 2014; Ramos da Silva, 2021). In universities, the adopted methodology is chosen based on careful analysis, considering the degree of difficulty of the content and the student's performance. However, the teacher must have full command of the methodology used to stimulate the students' curiosity and maximize the effectiveness of learning (Morán, 2015; O'Flaherty & Phillips, 2015).

In engineering courses, active teaching is becoming increasingly necessary, as it encourages students to develop a diversified way of thinking that is aligned with the demands of the job market (Lara-Prieto et al., 2024). Several methods can be applied in the classroom, such as Problem-Based Learning (PBL), flipped classroom, case study, simulation, and gamification (Gallo et al., 2024; Valença, 2023).

PBL has been gaining ground in the classroom. It builds on Constructivist Pedagogy, and educators widely use it in engineering and economics courses. Its application has yielded positive results among students and significantly benefited the learning process. The main objective of this method is to encourage students to seek information independently and identify the key issues of a given topic, developing solutions for them (Souza et al., 2019; Tan, 2003).

The flipped classroom methodology aims to redefine the role of the teacher, introducing a new dynamic into classes. In this model, students study the proposed topic and then clearly share the knowledge they acquire with their classmates and the teacher, who now acts as the student's advisor (Lostada, 2017; Olivieri & Zampin,

2024). With the advancement of technology, educators have increasingly explored this method, as students now search for information online, whether in videos, slides, articles, or even podcasts (Gallo et al., 2024; Morán, 2015).

Another method is Gamification, although some educators still misinterpret its concept for teaching (Mohanty & Christopher B, 2023). Gamification is defined as "the use of game design elements in non-game contexts" (Deterding et al., 2011), and its main objective is to engage participants, encouraging them to understand and interpret the story and absorb the proposed knowledge (Koivisto & Hamari, 2019).

Experts define engineering economics as the science of designing real-world institutions and mechanisms that align behavior with individual goals and incentives. Although its name suggests a direct relationship with economics, this area of engineering focuses on finance, based on a key concept: "the time value of money" (Donizetti de Lima et al., 2017; Flemming, 2017). Understanding this concept requires students to develop problem-solving and decision-making skills and think broadly (Flemming, 2017; Zoghi, 2015).

For a professional in economic engineering, a necessary skill is to perform an economic analysis, which is an essential skill (Dym et al., 2005). An economic analysis aims to identify the short, medium, and long-term benefits or profits of a project or investment, determining which is the most viable to be applied and what the returns will be in the future (Zago et al., 2009). Analysts perform the calculation of this analysis through several methods, such as the Net Present Value (NPV), which brings the predicted value of each period of the project to the present, considering the Minimum Attractiveness Rate (MAR), which is the lowest expected return to consider an investment viable, and the Internal Rate of Return (IRR), which occurs when the NPV is equal to zero, and the Return on Investment Period (Payback), which refers to the time required for the investment to be recovered (Assaf, 2016).

3 Methodology

The research method was the systematic literature review (SLR), which maximizes the potential of a search by finding the highest possible number of results in a more organized manner. Based on the research question, criteria were determined for conducting the SLR without defining a minimum or maximum year of publication of the articles. This allows us to observe the evolution of interest in the academic community on the topic over the years.

The languages chosen were English and Portuguese. English was chosen due to its scope, and Portuguese due to the context of the study. The inclusion or exclusion criteria were guided by the main objective of the research, which was articles that addressed the topic within the context of engineering, specifically in the discipline of economic engineering. Thus, we included articles that met this main criterion in the analysis.

We selected a set of articles based on the Scopus and Web of Science databases. The chosen keywords were "Active Learning", " Flipped Classroom ", " Gamification ", " Learning Strategy ", " Problem-Based Learning", "Project-Based Learning", " Engineering ", "Economic" in titles, abstracts and/or keywords, to encompass active methodologies in the area of engineering and economic engineering. The review followed the protocol Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Moher et al. 2009).

We conducted the review in the Scopus and Web of Science databases, finding 630 and 651 articles, respectively, totaling 1281 articles. In the identification stage, we excluded articles that did not offer full access, leaving 319 articles remaining. Among the articles with full access, we excluded 42 articles because they were duplicates.

The remaining 277 articles went through the Screening stage, in which the criterion was the language used to write in Portuguese and English, resulting in the exclusion of 5 articles. After this stage, the Eligibility stage was carried out, with the reading of the title and abstract of the articles to verify eligibility, in which the criterion was "Articles that study and demonstrate in practice active methodologies in engineering courses with relevance to economics". Thus, we selected 16 articles for the Inclusion stage, which involved complete reading. In addition, we added articles based on the experts' recommendations, totaling 20 articles.

4 Results and discussion

We selected 20 articles that were analyzed qualitatively by reading, highlighting information such as the type of active method used, the objective of using the methodology, how the methodology was applied, the way of examining the results, and the quantitative results. Table 1 shows all the PB articles with their respective titles, year of publication, and authors.

Table 1 – Articles in the Bibliographic Portfolio and their respective authors.

Code	Title	Authors
1	Efficiency analysis of engineering classes: A DEA approach encompassing active learning and expositive classes towards quality education	Nocera et al. (2024)
2	Lessons from online and offline PBL in an engineering economics course under the Covid-19 pandemic	Kim (2023)
3	The Economic Evaluation of Projects as a Structuring Discipline of Learning Processes to Support Decision-Making in Sustainable Urban Transformations	Abundante et al. (2022)
4	Applying Problem Based Learning to Improve Student Engagement in an Engineering Economics Course	Donndelinger (2021)
5	Integrating Science, Technology, Engineering and Mathematics contents through PBL in an Industrial Engineering and Management first year program	Alves et al. (2019)
6	Applying Engineering Economic Analysis to Contemporary Problems with Global and Societal Implications	Bursic (2006)
7	Increasing the Use of Collaborative Learning Techniques in an Integrated Economics and Engineering Economy Course	Burtner & Moody (1999)
8	The Impact of Flipped Project-Based Learning on Self-Regulation in Higher Education	Zarouk et al. (2020)
9	Teaching Methods of Economics Contributing to Economic Competence of Bachelors of Engineering	Kostina et al. (2020)
10	Incorporating Active Learning Strategies into an Engineering Economics Course	Egbue (2018)
11	Computational Intelligence in Financial Engineering Trading Competition: A system for project-based learning	Chaidarun et al. (2015)
12	Work-in-progress: Soft-skills development for higher education engineering and economic students using HERA collaborative serious games	Caeiro-Rodriguez et al. (2020)
13	The effect of challenge-based gamification on learning: An experiment in the context of statistics education	Legaki et al. (2020)
14	Using Gamification for Teaching Economics in Technical Higher Education: An Exploratory Research	Simionescu (2017)
15	Game of engineering economic	Weise et al. (2013)
16	Interactive Simulation for Teaching Engineering Economics	Dahm (2002)
17	Engineering Economics Analysis Course – from Flipped Classroom to Distance Teaching	Mendez-Piñero (2020)
18	Flipped classroom experiences and their impact on engineering students' attitudes towards university-level mathematics	Turra et al. (2019)
19	Evolution of a Flipped Engineering Economy Course	Lavelle et al. (2015)
20	Teaching sustainable design using engineering economics	Turner (1998)

As a result of the PB, the methodologies can be grouped into four (4) methods used: PBL, gamification, flipped classroom, and simulation, which is demonstrated in Figure 1. In Figure 1, the four quadrants can be seen, with the numbers in green representing articles applied in economic engineering.

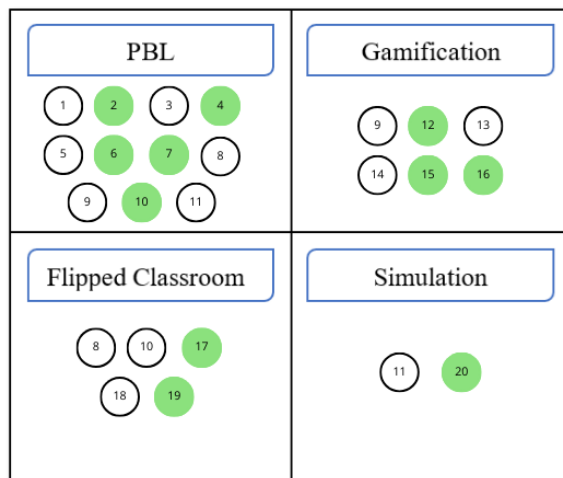


Figure 1 – Active methodologies and their respective articles

PBL was the most used method found in 55% of the articles. Of this total, 45.5% were applied in Economic engineering. The results regarding the implementation of PBL in the course were positive, fulfilling the general objectives of the methodology to increase student engagement in the course and to help in decision-making in the economic area, improving the understanding of the main concepts of economic viability. Donndelinger (2021) applied PBL in the form of personal financial planning and tax consultancy, so that students could make better decisions regarding the content and also increase their academic performance. The study highlighted as main results the significant positive impact on students' engagement and academic performance, with an increase of 2.1 points on a scale of 6 about interest in the subject in class.

Researchers applied gamification in 30% of the articles, with 25% of these focusing on Economic engineering. The main objectives for using this methodology are to make learning more dynamic, facilitating understanding economic concepts more interactively, and motivating students through games. According to Simionescu (2017), 91% of students who participated in this methodology stated that gamification contributed to an increase in academic performance, helping them to better assimilate information related to Economic engineering. Likewise, 75% of students reported that they found the experience satisfactory, leading the study to conclude that the methodology positively impacted student engagement and motivation in relation to the subject.

Researchers used the flipped classroom as the third most common method in 25% of the articles, applying it to economic engineering in 60% of these cases. The main objectives of applying this methodology were to improve the effectiveness of teaching in engineering, improve the learning experience, and keep students engaged in the subjects.

At the pandemic's beginning, Méndez-Piñero (2020) used the flipped classroom in an Economic engineering course, adopting remote teaching, to keep students engaged. The author prepared theoretical content on the value of money over time and proposed exercises related to the topic, so that, during synchronous classes, students could ask specific questions and help each other even more. The analysis of student performance, based on final grades over 3 years, indicated a growing improvement trend positively impacting students' engagement and learning experience with this method's application. The study states that the approach

improves the teaching of Economic engineering, even with the difficulties faced during the COVID-19 pandemic.

The methodology identified in 10% of the articles was simulation, and 50% of the applications occurred in economic engineering. The main objective of this methodology is to create immersive and realistic learning environments so that students can practice and apply prior knowledge and make their own choices within this environment (Huttar & Brintzenhofeszoc, 2019).

Chaidarun et al. (2014) used simulation by having students create a fictitious center for sustainable education, allowing them to apply the concepts learned practically and realistically. The author's primary focus was to increase the course's evolution over the years in relation to economic analysis. To measure this parameter, methods such as student feedback, satisfaction surveys, and group discussions were used.

As a result, the author indicates that the course's evolution has flaws and successes, with student evaluations above average over the years, which was related to a positive perception of the course, suggesting that students valued the learning experience. Furthermore, he concluded that the simulation contributed to the training of engineers, making them understand the technical aspects of their profession and address issues of sustainability and economic viability in their projects.

The results analyzed show that the concepts addressed in the economic engineering disciplines can generate doubts and are difficult to interpret, leading teachers to reinvent themselves when teaching the content. Furthermore, we can conclude that PBL achieved a high approval rate among students and is also the most frequently used method in combination with other methodologies. These findings corroborate the results Gallo et al. (2024) found, which identify PBL as the most suitable method for teaching economic engineering.

5 Conclusion

The research presented the main studies on active methodologies applied to economic engineering, achieving the study's objective by providing a quantitative analysis and qualitative research. The latter exposed the main findings of the articles by surveying the number of articles developed in the four methods used. In this study, we found 1281 articles, which, after applying the PRISMA method, resulted in a bibliographic portfolio of 20 articles.

According to all the analyses, PBL stands out among the four main methods in terms of number of publications, applicability, and ease of understanding the topic. However, the combination of methodologies has also proven to be effective, presenting positive results and contributing to the improvement of the academic environment. Thus, all methodologies are important, but in-depth knowledge of each method is necessary to ensure that it does not hinder understanding the content covered.

During the process of this study, it was difficult to find articles that directly addressed the topic in economic engineering, (we adjusted the keywords several times) requiring several adjustments to the search keywords, in addition to the inclusion of articles recommended by experts. As future perspectives, it is necessary to expand through empirical studies of active methodologies that aim to improve and engage teaching in economic engineering, which is a topic that contains specific and difficult to understand concepts.

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Actively Teaching the Teachers: Impact of a Professional Development Initiative for Early Career Staff in Higher Education

Tom O'Mahony¹, Sinead Huskisson², William Carey³

¹ Teaching and Learning Unit, Munster Technological University, Cork, Ireland. ORCID 0000-0002-0658-5797

² Department of Management & Enterprise, Munster Technological University, Cork, Ireland. ORCID 0000-0002-0962-9951

³ Senior Educational Developer, Nottingham Trent University, Nottingham, UK.

Email: tom.omahony@mt.ie, sinead.huskisson@mtu.ie, william.carey@ntu.ac.uk.

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Abstract

EAT-PD (Enabling Academic Transitions through Professional Development) is an innovative initiative that addresses a critical need in higher education: developing the teaching practices of early-career faculty to promote active, collaborative and inclusive teaching strategies. This one semester long, one hour per week, online, synchronous program introduces early-career faculty to active learning strategies through modelling these strategies. Example strategies include classroom-response systems, discussions, peer-instruction, flipped classroom and team-based learning. While large-scale classroom observation studies continue to establish the need for instructional development programs within higher education, the impact of existing programs on classroom practices is contested. Therefore, this article contributes by adopting a quasi-experimental pre-test/post-test design to evaluate the impact of the EAT-PD program on the instructional practices of participants. Participants completed a pre-survey (n=51) and post-survey (n=34) which explored the frequency of use of specific teaching strategies during that time-period. Pre and post responses showed a statistically significant difference for questions relating to the frequency with which participants put students into pairs or small groups for extended time periods during class and for the question related to soliciting student feedback. Additionally, content analysis was used to code responses to a mid-semester survey (n=49). This data revealed that experiencing active learning strategies within a peer-supported environment were keys to the success of the EAT-PD instructional development initiative. Future research will explore long-term impacts on teaching practice and student outcomes.

Keywords: Active Learning; early career faculty; instructional development; quasi-experimental design.

1 Introduction

A substantial body of evidence demonstrates that active learning positively impacts student learning and student outcomes for all learners (Freeman et al., 2014; Theobald et al., 2020). However, evidence from classroom observations suggest that traditional lectures continue to dominate higher education practice (Noben et al., 2022; Stains et al., 2018). As many academics enter teaching roles with limited pedagogical training, supporting early-career faculty to adopt active and evidence-based practices is critical to fostering long-term instructional excellence in higher education. Enabling Academic Transitions through Professional Development (EAT-PD) is an instructional development program for early-career Lecturers at Munster Technological University (MTU), Cork Ireland. To the authors' knowledge this initiative, with its focus on active learning for early-career faculty, is unique in the Higher Education sector in Ireland. Internationally, the impact of active learning instructional development initiatives on the actual classroom practices of higher education faculty is contested (Emery et al., 2020; Schmid et al., 2021). This article contributes by adopting a quasi-experimental pre-test/post-test design to evaluate the impact of a one-semester, online instructional development program that aims to support early-career faculty to adopt active learning instructional approaches. In doing so it establishes the link between instructional development and impact on teaching practices. This link is critically important as institutions aim to improve teaching effectiveness and support

academic transitions. Of equal importance is the need to evaluate the measurable impacts of instructional development programs and justify the resources invested in faculty development.

2 Literature Review

2.1 Active Learning

Active Learning can be defined as ‘a classroom situation in which the instructor and instructional activities explicitly afford students’ agency in learning’ (Lombardi et al., 2021, p. 15). A convincing body of research demonstrates the efficacy of active learning. For example, the meta-analysis conducted by Freeman et al. (2014) evidenced that active learning positively impacts learning achievement and reduces failure rates. This impact extends from Science, Technology, Engineering and Mathematics disciplines (Freeman et al., 2014) through to humanities and social science disciplines (Kozanitis & Nenciovici, 2023). Active learning has also been shown to reduce achievement gaps associated with underrepresented students (Theobald et al., 2020). Hence, ideas traditionally associated with active learning e.g. engagement and collaboration are increasingly prioritised in strategies designed to support equity and diversity, such as universal design for learning (Moriña et al., 2025).

However, despite this convincing body of evidence in favor of active learning as a pedagogy, the majority of faculty continue to use the more traditional lecture format in their own classrooms. For example, the large scale observation study conducted by Stains et al. (2018) revealed that lecture-based approaches are more common than active learning. A more recent study, consisting of 203 classroom observations, concluded that it was ‘striking that almost half of the observed lecturers did not demonstrate sufficient activating teaching behavior since the importance of active learning for student achievement has been well-established in higher education’ (Noben et al., 2022, p. 39). The authors also observed that while ‘lecturers might have the required knowledge related to these domains, they often struggle with implementing this knowledge into practice’ (Noben et al., 2022, p. 39). Studies exploring the integration of technology and assessment practices have arrived at similar conclusions – that traditional, instructor-centred practices dominate (Lillejord et al., 2018; Myers & Myers, 2015).

2.2 Faculty Implementation of Active Learning

Consequently, instructional developers have designed various initiatives to encourage faculty to adopt active learning pedagogies. Some of these initiatives have targeted early-career faculty, due to the recognition of substantial impact that initial teaching experiences can have on the personal and professional lives of academics (Feixas, 2002). One such initiative, the US-based Faculty Institutes for Reforming Science Teaching (FIRST) IV program, was aimed at biology postdoctoral researchers and ran from 2009 to 2013 (Emery et al., 2020). FIRST IV was a two-year program that focused on curriculum development and mentored teaching practicums. Over the course of the program, FIRST IV participants learned about and applied instructional strategies to engage students in learning the core biological concepts. Rigorous evaluations included teaching observations of FIRST IV participants compared with paired faculty i.e. faculty with a similar profile from the same department but had not participated in FIRST IV. FIRST IV participants demonstrated greater levels of active student engagement and implemented more learner-centered classrooms than their peers and this change persisted long after (6 to 9 years) participation in FIRST IV (Emery et al., 2020). Viskupic et al. (2019, p. 201) also used classroom observations and report that ‘that instructors with at least 24 h of PD are significantly more likely to teach a Student-Centered class than instructors with fewer hours’ and that those odds increase if the instructional development undertaken is discipline-specific. Meizlish et al. (2018) drew on student course evaluations to explore the impact on faculty who had undertaken instructional development relative to a

control group. Their data demonstrated statistically significant positive effects in relation to overall course ratings, instructor ratings and self-reported learning gains.

Findings from other studies reveal the contested impact of instructional development programs. Evaluations of instructional development initiatives undertaken in Belgium, China and the US evidenced a positive impact on self-efficacy and conceptions of teaching but little impact on teaching behavior and no improvement in student learning (Favre et al., 2021; Greer et al., 2021; Stes & Van Petegem, 2011). Using a quasi-experimental design that explored impact based on course design and classroom observations, Schmid et al. (2021) report that early-career participants performed similarly to the control group that did not participate in instructional development. Gebru (2016, p. 1741) observed that their early-career participants' 'teaching practice still largely draws from their previous teachers' indicating that the instructional development program was not fully effective. Ross et al. (2020) explored the impact of a two-year instructional development program on engineering faculty in the US. While classroom observations indicated 'positive shifts in active learning strategies in the classroom' the overall analysis suggested that participating in the program did not impact student achievement (Ross et al., 2020, p. 14).

So, despite the convincing evidence in favor of active learning pedagogies, the majority of faculty persist with more traditional lecture-based formats (Noben et al., 2022; Stains et al., 2018). This persistence points to the need for instructional development that aims to transform classroom-based practices. Focusing on early-career academics is advantageous due to their potential longevity within the university system and they key role that those initial years play in building academics' identity, socialization and practice (Feixas, 2002; Kelchtermans, 2019). The neo-liberal agenda and tight budgets within with many universities operate, places an increasing demand to establish the efficacy of instructional development initiatives and to evidence that investment in instructional development has been worthwhile. This study contributes by establishing the link between early-career participation in an instructional development program and changes in teaching practice.

3 Research Method

The research question addressed by this study is:

- (1) To what extent does participation in the EAT-PD program increase instructors' use of active learning strategies within their own classrooms?

3.1 EAT-PD Instructional Development Program

The EAT-PD Instructional Development program targets early career faculty³ at MTU. The aim of the EAT-PD initiative is to challenge traditional conceptions of teaching and encouraging the adoption of active and collaborative instructional approaches. EAT-PD is a 12-week long program that is delivered on-line using a mixture of weekly 1-hour synchronous sessions and recommended resources hosted on a Learning Management System platform. The initiative focuses on discussing and modelling active learning strategies including the use of interactive polling tools, think-pair-share, small group discussions, peer-instruction, team-based learning and the flipped classroom. The initiative also highlights how active learning is inclusive and effectively reduces the achievement gap associated with underrepresented students in higher education (Theobald et al., 2020). As outputs, participants are asked to develop a Module Enhancement Plan which outlines how active learning strategies could be used to solve a teaching and learning challenge participants are experiencing and develop a 1,400 word reflective account of practice to meet the requirements for Associate Fellowship of Advance HE (*Associate Fellowship*, 2025). Advance HE is a UK-based charity that aims

³ At MTU early-career is defined as faculty employed by the university for three years or less in a full-time or part-time capacity

to improve higher education for staff, students and society. Fellowships are awarded based on evidence that personal practice meets the requirements of the teaching and learning standards framework for the higher education section (Advance HE, 2023).

3.2 Research Approach

The study adopts a mixed-methods approach combining a quasi-experimental pre-test/post-test design to measure changes in participants' reported practices along with an open-ended survey to explore their experiences of the EAT-PD instructional development program. The use of pre- and post-surveys enables assessment of effectiveness by comparing baseline and post-intervention practices, and allows for a statistical analysis of change over time. The pre-test survey was administered during the first meeting with each cohort, the post-test was administered during the last meeting with each cohort while the open-ended survey was administered mid-way through the initiative. All data was collected via anonymous online instruments.

3.3 Participants

The authors ran the EAT-PD program in January - June 2020, Sept. – Dec 2020, January – June 2021, January – June 2024 and Sept. – Dec 2024. A colleague ran the program in the intervening years 2021 and 2024 but data was not collected. Over these five semesters 85 early-career faculty participated in the program. 51 participants responded to the pre-survey instrument, 34 to the post-survey and 49 participants responded to the open-ended mid-semester survey.

3.4 Data Analysis

As the quantitative pre- and post-survey data was collected anonymously and have unequal sample sizes, it was not possible to pair responses. Consequently, following Levene's test to establish equal variance, a two-sample (Independent) t-test with equal variances was used to statistically analyze the responses. Open ended responses were inductively coded. A descriptive coding approach was adopted as Saldaña (2021) advises that descriptive codes are useful for capturing 'what is talked about'. The frequency with which these codes appeared in the data was then counted to get a sense of the relative importance of the various experiences represented in the data.

4 Findings

Table 1 presents a statistical analysis of the pre- and post-survey results with the Likert *scale* never being mapped to 0 and *every class* being mapped to 4. This analysis reveals that statistically significant results were found for two questions. Participants reported that, subsequent to the EAT-PD intervention, they were more likely to implement small group, collaborative learning approaches for MOST of the class period and more likely to solicit student feedback to enhance their own teaching practice ($p < 0.01$). The question asking whether participants assigned more out-of-class work to individuals subsequent to participating in the instructional development intervention was almost statistically significant at the 5% level ($p = 0.059$).

Table 1: Statistical analysis of the pre- and post-survey items using a two-sample (Independent) t-test with equal variances

Survey Question	Average			p-value
	Pre	Post	Post-Pre	
Q5. How often do you lecture for most of the class period?	3.13	2.91	-0.22	0.252
Q6. How often do you use demonstrations in class (live or multimedia)?	2.83	2.82	-0.01	0.985
Q7. How often do you address questions to the class as a whole?	3.56	3.56	0.00	0.995

Q8. How often do you put students into pairs or small groups for brief intervals during class to answer questions, solve problems or discuss concepts/issues?	2.31	2.53	0.22	0.272
Q9. How often do you put students into pairs or small groups for MOST of a class period to answer questions, solve problems or discuss an issue?	1.58	2.09	0.51	0.004**
Q10. How often do you assign homework (out of class work) to individuals (as opposed to teams)?	2.08	2.5	0.42	0.059*
Q11. How often do you give students the option of working in teams (2 or more) to complete homework or assignments?	1.54	1.62	0.08	0.625
Q12. How often do you give a writing assignment (any exercise that requires explanations and not just calculations)?	1.92	2.18	0.26	0.119
Q14. Have you solicited student feedback for the purpose of improving your teaching during the last semester?	0.60	0.88	0.28	0.002**

** significant at the 1% level ($p < 0.001$); * almost significant at the 5% level ($p < 0.05$)

Table 2 presents the findings from the qualitative analysis. The first column presents the descriptive codes that were derived from responses to the open-ended question, the second column presents the frequency with which these codes appeared in the data while the final column presents representative quotes from participants. Table 2 evidences that direct exposure to active learning and experiencing the benefits associated with peer-learning positively impacted participants as did learning about active learning and specific active learning strategies. Participants praised the EAT-PD instructional development program, finding it useful and enjoyable and, to a lesser extent, that it positively impacted confidence levels. In relation to enhancing EAT-PD, participants suggested that sharing more resources on active learning and more specific examples of how active learning strategies have been implemented by faculty in different disciplines would be useful.

Table 2: Qualitative analysis of the open-ended mid-semester survey data

Code	Freq.	Representative Quotes from Participants
Peer learning	32	'The group workshops and the fact that we are able to develop and share ideas with our peers before reflecting them back to the class group. I find this an effective way to learn' 'The open discussion forum whereby you can learn from the experience of others. It helps you realise that other lecturers face the same issues and challenges' 'Hearing other peoples' perspectives' 'I find having a cohort of fellow lecturers from different departments is very useful as we can learn how different teaching principles can be applied across disciplines'
Active learning	26	'Learning about active teaching methods - looking at the research, examples and case studies' 'The opportunity to explore different types of active learning' 'Some of the practical techniques and approaches around reinforcing learning, peer learning and group discussions in class etc I have already applied with some success, I hope!'
Useful	18	'I am benefiting and learning a lot from these classes' 'All of the techniques are simple and very practical and could be adopted immediately in my current teaching practice'
Enjoyable	14	'I am really enjoying the course and I know it has already improved my teaching skills, I have been able to apply some of the strategies to the (virtual) classroom' 'I am enjoying the course immensely'

Course content	11	'The content is generally very informative and interesting' 'The carefully curated reading material and research given on the course gives me the direction to focus on important areas to promote a better teaching environment'
Praise	11	'Great initiative, it is really informative' 'I think the program has been brilliant thus far without any real limitations'
Specific examples	8	'I find it very helpful when more experienced lectures share tools they use successfully in their classes. More of these discussions would be great' 'Maybe more insights from other peoples' experiences from teaching, what worked well and what didn't work well, insight from people who had to deal with poor class attendance'
More resources	8	'In general, some more literature would be beneficial I think' 'More online resources for self-study on teaching practices and methods'
Confidence	6	'It has given me a newfound confidence in not just my teaching but in all my dealings at MTU' 'I am really enjoying this module and finding that it is greatly improving my confidence in the classroom'

5 Discussion

Research on faculty instructional development reveals that initiatives that are active and longer duration are more impactful (Stes & Van Petegem, 2011; Viskupic et al., 2019). Aligning with the literature on learning in general (Freeman et al., 2014; Weimer, 2013), the literature on instructional development identifies the impact of collaborative approaches where faculty share and learn from each other (Dancy et al., 2016; Desimone, 2009). This evidence base informed the design of the EAT-PD initiative and the decisions that it should run over one semester and that the initiative would focus on modelling active learning strategies so that participants could experience the benefits of peer-learning. The qualitative data suggests that experiencing active learning first-hand was important in supporting participants to develop their instructional practices. Participants frequently mentioned the usefulness of small group discussions e.g. 'tasks where we were given something to read and discuss together in break out rooms have been helpful' and 'we are able to develop and share ideas with our peers before reflecting them back to the class group. I find this an effective way to learn'. Participants also highlighted how they learnt from peers. Hearing about the 'challenges experienced by other colleagues' and learning 'different techniques to address these' was highly valued by participants. This sharing of experiences helped normalize challenges for these early-career faculty and provided a supportive environment for exploring perspectives and ideas. Consequently, participants report that they found 'the active learning [in] small groups', 'shared learning between peers in class' and 'learning from others' very beneficial. In the words of one participant 'my own experience as a student on this program has shown me that groupwork is hugely valuable'. Consequently, we contend that this practical experience of collaborative learning and peer dialogue — where staff could share challenges, strategies, and build confidence *together* — helps explain why EAT-PD was impactful in supporting participants to enhance their own classroom practices.

Additionally, participants highlighted how EAT-PD provided them with the direct exposure to active learning as a pedagogy along with practical strategies, tools and concrete examples that could be easily implemented or transferred into their teaching practices. The program helped participants to understand that 'lecturing is not an effective means of learning' and 'to reduce the content I am delivering' to 'ensure that students are learning'. Participants highlighted simple but practical strategies such as breaking hour-long classes into '12min lecture, activity, 12min lecture, etc'. Participants reported that there was a good balance between 'the general benefits of active learning as a whole and specific strategies that can be utilized to create an active learning

environment' and how EAT-PD has 'given me useful strategies to promote better engagement and given me tools to deliver a more effective teaching strategy'. This specific focus on pedagogy and practice when coupled with opportunities to learn 'from other lectures about approaches to student engagement' provided a framework for enhancing practice.

It is likely that hearing about successful implementations from others and experiencing the benefits of active learning themselves increased participants' confidence to implement active learning in their own classes. The qualitative data contains some evidence that the program provided a space to 'try out new theories and techniques each week'. Participants report using tools such as Mentimeter and Jamboard, along with in-class quizzes and peer-instruction. Participants report how adopting these tools impacted student engagement i.e. that they 'found the engagement was better than putting a question to the class and getting blank faces looking back at me', it was 'very helpful to get students to engage more' and how 'the students love seeing the real-time data collection and participation has been very high'. Overall, this qualitative data helps to both support the result that participants are moving towards more learner-centered practices by implementing collaborative approaches for longer durations in the actual classrooms and also helps to explain why EAT-PD may have had this statistically significant impact. Assigning out-of-class work is likely to be related to this impact and faculty are likely to be assigning reading or moving towards flipped classroom approaches to create the space for more active learning in the classroom. It is also likely that with more data this item will become statistically significant.

More recently, academic developers' role in creating 'an environment of trust, in which our colleagues feel supported and valued' has been highlighted (Dransfield et al., 2024). McDonagh & Sanders (2025) explore the building blocks of trust and identified overarching themes which included opportunities for meaningful development, safety, positivity and support, reciprocity/genuine collaboration. We see direct parallels between these themes and the categories useful, course content, peer learning, enjoyable, praise identified in Table 2. Hence relational pedagogy, which views meaningful relationships as fundamental to learning, may also explain the success of EAT-PD.

5.1 Limitations

While the study provides valuable insights into the impact of instructional development on early-career faculty, the reliance on self-reported data is a limitation. The concern is supported by studies that demonstrate a gap between what instructors perceive that they do in the classroom and what is actually observed (Ebert-May et al., 2011) or reported by students (Borda et al., 2020). The response rate declined between the pre- and post-survey instruments (from 51 to 34 participants), which impacts the robustness of the statistical comparisons. We plan to continue to collect data over the coming semesters which should help to address this concern. As this data was collected immediately after the program completed, we do not know if this impact was sustained over the longer term. This is something we also hope to explore in the future. Finally, as the study focused on a single institution and instructional program, the findings may not be generalizable to other contexts or faculty development initiatives.

6 Conclusion

This study highlights the potential of well-designed instructional development initiatives to meaningfully shift early-career faculty toward more active teaching practices. The EAT-PD program demonstrated a statistically significant impact on participants' use of extended collaborative learning. This finding is supported by strong qualitative evidence that faculty gained both the knowledge and practical tools necessary to implement active learning immediately. The data suggests that experiencing active learning strategies and the sharing of

experiences within a peer-supported environment were keys to success and allowed participants to reflect on and reframe their own instructional approaches.

Although the study is limited by self-reported data and declining survey response rates, the findings suggest that programs which combine theory, peer interaction, and practical application are particularly effective in promoting change. Further research could explore long-term impacts on teaching practice and student outcomes, as well as how such programs can be scaled and adapted across institutional contexts.

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Tutoring and mentoring Industrial Engineering and Management freshman-students in Project-Based Learning

Anabela C. Alves¹, Senhorinha Teixeira¹, Cristina Rodrigues¹, Carina Pimentel¹, José Pedro Domingues¹, Susana Costa¹, Teresa Monteiro¹, Ismael Vaz¹, Celina P. Leão¹

¹ ALGORITMI/LASI R&D Centre, Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal

Email: anabela@dps.uminho.pt, st@dps.uminho.pt, crodrigues@dps.uminho.pt, carina.pimentel@dps.uminho.pt, pdomingues@dps.uminho.pt, susana.costa@dps.uminho.pt, tm@dps.uminho.pt, aivaz@dps.uminho.pt, cpl@dps.uminho.pt

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Abstract

Tutors and mentors are key supporting first-year students in Project-Based Learning (PBL), especially in engineering education. This study explores the roles of faculty tutors and alumni mentors in a first-year PBL course at the University of Minho, gathering feedback from students and those in support roles. A case study approach was used, combining two online questionnaires – one for students and another for tutors and mentors. Students rated their tutors and mentors across several dimensions: communication, availability, support, and motivation. Additional insights were gathered through open comments and focus group discussions. Results showed that both roles were appreciated but seen as different. Recent graduates as mentors often received slightly higher scores in team motivation and emotional support. Tutors were more closely linked to academic guidance and peer assessment. Only one item related to peer feedback was rated higher for tutors. Tutors and mentors generally found the experience rewarding but pointed out challenges with student engagement. The study highlights the importance of clearly defining each role from the start. Combining academic and peer-level support enhances the learning experience and may help first-year students navigate PBL more confidently.

Keywords: Active Learning; Project-Based Learning; Industrial Engineering and Management Education.

1 Introduction

There is an ongoing discussion on integrating Artificial Intelligence (AI) in education (Majeed & Hwang, 2024; Rahayu, 2023; Ravaglia, 2024). Simultaneously in industry, human-centric approach is strongly emphasized and it is one of the pillars for Industry 5.0 (Breque et al., 2021). At first, these ideas might seem at odds and a paradox: AI in education and human-centric in industry, bringing AI into classrooms while insisting on keeping people at the centre of industrial development. The education and industry world are using common tools, shared challenges, and the need for more integrated thinking. They are closer than before, and need to be, particular, in an Engineering Education context. Importantly, embracing new tools and methods does not imply abandoning the strengths of traditional practices, namely, demanding excellent teachers and tutors.

In Engineering Education, where active learning methodologies are increasingly being implemented, using traditional and recent tools (Alves & van Hattum-Janssen, 2022; Lima et al., 2024), teachers and tutors remain the most important knowledge source. They are emphatic, have a sacred trust (Schmier, 2001), and are flexible, helping students in this new Volatile, Uncertain, Complex, and Ambiguous (VUCA) world and, at the same time, Brittle, Anxious, Nonlinear, and Incomprehensible (BRITE) world (Figueiredo, 2023).

In Project-Based Learning (PBL), an active and centred-student learning methodology, it is recognized that a tutor has a critical role (Fernandes et al., 2009; Grunefeld & Silén, 2000; Powell, 2004; Powell & Weenk, 2003; Simão et al., 2008; Weenk et al., 2004). In particular, in Project-Led Engineering Education (PLEE), Powell and Weenk (2003) referred to what students can expect from the tutor:

- Keep to agreements made and promptly follow up on previously agreed actions;
- Read submitted parts of reports, logbooks, and worksheets quickly;

- Should not be too directive - he facilitates progress and does not solve the teams' problems himself;
- Be honest and do not always say everything is fine, especially when not;
- Be prepared to consider other opinions;
- Consult with other PLEE tutors as necessary;
- Gives positive feedback.

According to Simão et al. (2015), tutelage in Higher Education can be done by teachers included or not in the curricular units (CU) of the semester, researchers, or upper classes students. In addition, various kinds of tutoring, such as mentoring, curricular tutoring, academic tutoring, and training-related tutoring, have been implemented by Higher Educational Institutions as a response to the needs diagnosed among students (Simão et al., 2008). Although similar, tutoring and mentorship have differences (Colvin & Ashman, 2010; Lorenzetti et al., 2019; Terrion & Leonard, 2007). While peer tutoring typically focuses on a more advanced student helping lower-level students with course content, peer mentoring focuses on a more experienced student helping a less experienced student improve overall academic performance, encourages mentors' personal growth, and provides advice, support, and knowledge to the mentee (Colvin & Ashman, 2010).

Tutoring has always been a requisite of PBL implemented since 2004_05 in the first year of Industrial Engineering and Management (IEM) at the University of Minho (Alves et al., 2012; Lima et al., 2007). This tutoring suffered three main changes: 1) only one tutor by a team that was a teacher of a CU (Alves, Sousa, Fernandes, et al., 2016; Alves et al., 2007; Alves et al., 2010; Fernandes et al., 2009), 2) only faculty member, not teacher in this particular year, 3) a faculty member and a third year student by each team (Alves, Moreira, Leão, et al., 2017; Leão et al., 2022).

Pursuing a continuous improvement journey involving action-research cycles (Alves et al., 2020; Alves, Moreira, Fernandes, et al., 2017; Alves & Leão, 2015) motivates these changes. This paper appears as a consequence of this journey. It presents and compares the tutoring by a faculty member and mentoring by IEM alumni from students' perspectives, which support the teams' academic development in a PBL context. In addition, it presents the tutoring experience from the faculty members' and mentors' perspectives.

This paper is organized into six sections. After this first section, section 2 presents the materials and methods used to collect feedback for the study. Section 3 offers an overview of the IEM first-year, first-semester, focused in Integrated Project in IEM and tutor role and functions on this curricular unit. Section 4 presents the students' results and feedback regarding the role of tutors and mentors. Section 5 presents the tutors and mentors perspective regarding their tutelage experience. Finally, the last section draws conclusions based on the findings.

2 Materials and methods

The research strategy employed in this paper was a case study focusing on the 2024/2025 cohort of 70 students enrolled in the first semester of the first year of the IEM Bachelor's program. To gather student's perspectives, the research team administered an online questionnaire at the end of the semester. This questionnaire, "Learning by project: tutor's assessment," is available in Alves et al. (2017). One of the initial questions in the questionnaire asked students to indicate which type of tutor they were evaluation – either a faculty member or an IEM alumni. It is composed of a total of 37 questions divided into 10 sections. The closed items (34) are scored on a Likert scale [1: Totally disagree to 5: Totally agree]. The remaining three items were open questions.

In addition, the results of a focus group developed in the final workshop were used to examine various dimensions, including the tutor's role topic. Twenty-four students, one tutor and two teachers participate in this focus group. Figure 1 presents a moment of the final workshop where students work in groups on the dimensions more critical during the PBL process: 1) Peer review; 2) Report assessment by groups; 3) Role of

the tutor; 4) Integration of the curricular units into the project; 5) IEM@ProjectNetworking; and 6) Support and feedback from teachers.



Figure 1. Focus groups during the final workshop

Seventy-one fulfilled the questionnaires, 33 regarding the tutor role and 38 regarding the mentor role, which represents a 51% response rate. For this kind of study, that is enough to examine the results and compare the two types of tutelage. While more answers would be better, these still show students felt about the support they received. Furthermore, to collect the tutors' and mentors' perspectives, a different online-questionnaire, "Tutor experience evaluation," was used, which is also available in Alves et al. (2017). This questionnaire was divided into seven sections and has 22 items. Six were open questions. Fourteen completed questionnaires were obtained (only two faculty members did not fulfill the questionnaire), corresponding to an 88% response rate.

The main research questions focused on this study are:

1. What are the students' perspectives regarding the performance of tutors/mentors in PBL context?
2. Do tutors and mentors play tutors' role similarly?
3. How was the tutoring/mentoring experience?

3 Study context

The Bachelor's Degree in Industrial Engineering and Management (IEM) at the University of Minho introduced Project-Based Learning (PBL) in the 2004-2005 academic year as a way to make learning more engaging and practical (Alves et al., 2020; Alves et al., 2021; Lima et al., 2007). It started with interdisciplinary projects in the first semester and became a formal part of the curriculum in 2012-2013, with the course Integrated Project in Industrial Engineering and Management I (IPIEM1). This course brings together knowledge from different disciplines within the IEM program (Alves et al., 2014).

Over the years, the course has evolved. Adjustments were made to improve how it runs and to better support students and teachers (Alves, Sousa, Moreira, et al., 2016; Alves, Moreira, Fernandes, et al., 2017). Table 1 lists all the Project Supporting Courses (PSCs) involved in the latest editions of IPIEM1. These courses come from two schools (Sciences and Engineering) and three departments (Mathematics, Production and Systems, and Information Technologies).

Table 1. Courses of the 1st year, 1st semester, of the IEM program

Regime	Curricular Unit	Scientific Area	ECTS
Year 1			60
S1	Calculus for Engineering	M	5
S1	Computer Programming I	CE	5
S1	Integrated Project in Industrial Engineering and Management I	EIS	5
S1	Introduction to Economics Engineering	EIS	5
S1	Introduction to Industrial Engineering and Management	EIS	5
S1	Linear Algebra for Engineering	M	5

Through learning by doing, students connect technical knowledge to real-world situations. This method supports deeper learning and helps students retain knowledge over time. In addition to the technical skills from the PSCs, students also develop transversal skills like teamwork, communication, conflict management and critical-thinking. Although challenging, the PBL experience gives students many opportunities to grow in both academic and soft skill areas.

3.1 Integrated Project in Industrial Engineering and Management 1

The IPIEM1 is a project-based course where students work in teams, supported by tutors, to solve real-world problems. Each team, typically made up of seven to nine students, develops a project often focused on sustainability (Alves, Moreira, Leão, et al., 2017; Alves et al., 2024; Colombo et al., 2015; Moreira et al., 2011). Along the way, students apply technical knowledge from different subjects and develop various transversal skills such as teamwork, creativity, and conflict management.

Each team receives the Project Guide at the start of the semester to guide their work. This document, prepared by the coordination team, outlines how the IPIEM1 is organized and what is expected from students and tutors. It includes: 1) an overview of the IPIEM1 model and key references; 2) the list of coordinators, teachers, and tutors, and their contact details; 3) the project theme and main goals; 4) a description of the tutors' roles; 5) learning outcomes for each PSC; 6) the assessment model for both IPIEM1 and the PSCs; 7) information about resources available (e.g. project rooms); and 8) details about the e-learning platform used in the course.

Throughout the semester, feedback is collected from students, teachers, tutors and educational researchers to monitor the project's progress and improve the learning process. At the end of the semester, a final workshop is held. In this workshop, survey results, assessment outcomes, and reflections on the project experience are discussed. The workshop begins with small group discussions, following focus group principles, and ends with a collective sharing of ideas and conclusions.

3.2 Tutor role and functions

In the 2024/2025 edition, each student team was supported by one faculty tutor and one alumni mentor. The tutor is a faculty member from the Department of Production and Systems (DPS), who was not involved in teaching first-year courses of that semester. The mentor, IEM alumni, brought a professional perspective; sharing insights from industry and helping students navigate their first-year experience. All eight alumni mentors had completed their degrees within the past five years, and all but one had taken part in IPIEM1 PBL as students. Having previously worked with tutors during their first year, they could now support new students from a peer and professional standpoint. Both roles were taken on voluntarily and offered different but complementary support forms.

The faculty tutor played a more academic and procedural role. According to the Project Guide, their responsibilities included:

- Monitoring the team's progress of the project and the development of relevant skills.
- Supporting the peer assessment process by explaining how to apply the criteria and use the required tools.
- Reviewing the individual peer assessments and discussing the outcomes with the team to encourage fair and honest evaluation.
- Observing individual contributions to identify students who might be struggling.
- Reporting the team's progress to the coordination team and passing along any updates or concerns.
- Communicating with PSC teachers about specific academic difficulties observed in the team.

The IEM *alumni* mentors offered informal and peer-level support. They helped students adjust to university life, explained how to access services, and encouraged good team dynamics. Mentors also introduced students

to professional opportunities and networks, such as “*Núcleo de Estudantes de Engenharia e Gestão Industrial da Universidade do Minho*” (NEEGIUM, the IEM student association) and European Students of Industrial Engineering and Management (ESTIEM). They often shared their academic and career experiences, offering advice and guidance from a recent graduate’s perspective.

4 Students’ perspectives on faculty tutors and *alumni* mentors

This part of the study focus on how students perceived the support and performance provided by faculty tutors and alumni mentors. Data were gathered through questionnaires and focus groups conducted at the end of the semester. With this section, is answered the first research question: “*What are the students’ perspectives regarding the performance of tutors/mentors in PBL context?*”

4.1 Questionnaire results

The online questionnaire is a combined one where the first initial question is for students to indicate which type of tutor they were assessing: the faculty member or the IEM *alumni* mentor. The following sections presents the results.

4.1.1 Faculty tutors

A total of 33 students out of 70 enrolled answered to the questionnaire. The answers came from students in all eight projects teams (G1 to G8), with the distribution of responses per team varied, ranged from 1 (G1) to 6 (G3, G6, and G8), with most answers coming from Groups G2, G3, G5, G6, and G8. In terms of gender, the sample was balanced, with 17 female and 16 male respondents.

As part of the questionnaire, students were asked to rate the overall performance of their faculty tutor on a scale from 1 to 10. The answers showed a broad range of scores, 5.3 to 10, with an average rating of 7.3. In some cases, the evaluation was based on feedback from just one or two students, while in others, several team members contributed to the score, offering a more representative view.

In the open comments, students highlighted several positive aspects of the support provided by their tutors. Many valued the help clarifying the project’s objective, making sense of the peer assessment process and its outcomes, and creating a supportive and collaborative team environment. Some also emphasized the tutor’s role in guiding the team through challenging moments and encouraging thoughtful decision-making. However, feedback regarding availability was more mixed – while some students felt that their tutor was accessible and responsive, others preferred regular contact or proactive engagement. These varied perceptions point to a gap between student expectations and how the tutor’s role was experienced, particularly regarding accessibility and presence throughout the project.

Among the open comments, by one hand, one student praised the tutor’s role in team cohesion, stating: “*The tutor kept the team together during the most difficult moments.*” On the other hand, another student expressed a desire for more consistent support, suggesting the tutor could “*be more present and available to help us through the various challenges we faced.*” These contrasting views reflect the diversity of student expectations and experiences regarding tutor engagement.

4.1.2 IEM *alumni* mentors

A total of 38 students answered to the IEM alumni mentor questionnaire, representing all eight project teams (G1 to G8). The group was slightly female-majority, with 21 female and 17 male students. The number of responses per team ranged from 2 to 8, with the highest participation in Groups G2 and G6.

Students rated their mentor between 4 and 10 on a 10-point scale, with the median score across teams ranging from 6.0 to 9.0 (average score of 8.3). The average ratings were also consistently high, suggesting that students

appreciated the support received from mentors. Some teams showed very consistent responses among members (standard deviation smaller than 1), while others had a wider spread of opinions. This variation may reflect differences in how mentors interacted with their teams or how students interpreted their role. Overall, data suggest that the alumni mentors played a valuable role in guiding and supporting first-year students throughout the project experience.

The open-ended answers paint a largely positive picture of the mentors' involvement. Students frequently praised the mentors for their support in clarifying doubts and offering guidance, particularly during stressful or uncertain stages of the project. Comments such as "helped the team stay united," "offered valuable feedback that helped us complete key tasks," and "guided us in the right direction, especially at the beginning of the project" were common. Others highlighted contributions to team motivation and group dynamics: "helped us break the ice and improve communication," and "provided tools that really helped us work better as a team." These examples suggest that while mentors may not have been perceived as highly visible in terms of formal coordination or academic leadership, their peer-level presence and emotional support were valued.

When asked whether their expectations had been met, most students responded positively. However, a few noted that they would have appreciated a more consistent presence from the mentor throughout the entire project.

4.2 Focus group results

In the final workshop, students participated in small group discussions and completed feedback sheets on the tutor's role. The form had three parts: 1) the tutor corresponded/not corresponded to the expectations (give examples); 2) the tutor role could be improved: "Yes (e.g. to do some activities with the team)", "No. Why?" and 3) Other suggestions. Figure 2 presents the paper sheet fulfilled by a group of students.

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PAPEL DO TUTOR
O tutor correspondeu / não correspondeu às expectativas do grupo ... [exemplos - exemplos]. Identifiquem, p.f. se se referem a tutor-docente ou tutor-aluno.
Os tutores não correspondiam às nossas expectativas. Estávamos à espera que tivessem mais ~~emp~~ iniciativa. No entanto, quando pedíamos alguma coisa estavam disponíveis para ajudar. Neste caso referimo-nos aos 2 tutores.
O papel do tutor poderia ser melhorado?
- Sim: Como? (ex. fazer atividades específicas com as equipas, etc.)
- Não: Porque?
Podiam haver atividades presenciais para criar mais afinidade com os tutores, de modo a ~~estarmos~~ estarmos mais à vontade com eles e solicitar a sua ajuda mais frequentemente.
Outras Sugestões:

Figure 2. Example of completed paper sheet fulfilled by a group of students during the final workshop related to the tutor role (in Portuguese)

The first part of Figure 2 reflected a common issue mentioned by several students: the support they expected from tutors and mentors did not always match what they wanted. In this case, the group felt neither role fully

met their expectations. Although they recognised that both the tutor and mentor were available when needed, they wished they had been more present and involved during the project.

In the second part of the document, the students also suggest that more face-to-face contact could have helped build a better relationship. They wrote *"There could be more face-to-face activities to create more affinity with tutors, so we would feel more comfortable asking for help"*. This shows the importance of building trust early on, so students feel at ease reaching out. The students did not complete the third part of the document, which asked for further suggestions.

In PBL, tutors are not there to give answers or tell students exactly what to do. Their role is to ask questions, help students reflect, and guide them in taking responsibility for their learning. This approach can feel unfamiliar to students used to teaching that is more traditional. Their feedback suggests that explaining the tutor's role at the beginning – and returning to it during the semester – could help manage expectations and improve the overall experience. However, this was always did by the coordinator.

4.3 Comparing tutor and mentor roles

This section addresses the second research question: "Do tutors and mentors play tutors role similarly?" To answer this research question, the quantitative ratings from Likert-scale questions and open-ended student feedback was analyzed. The comparison of average scores across the complete questionnaire indicates that, while tutors and mentors were positively evaluated overall, students tended to rate mentors slightly higher on several dimensions - particularly those related to motivation, availability, and team dynamics.

Interestingly, slightly more students responded to the mentor evaluation (38) than to the tutor evaluation (33). This difference may reflect the nature of the mentor–student relationship. As recent graduates, mentors may be perceived as more approachable or relatable, which could make students feel more comfortable providing feedback.

To deepen the comparison between tutors and mentors, the 15 items with the most considerable differences in average scores as rated by students were identified. This selection was based purely on numerical differences without prior categorization. The corresponding heatmap (Figure 3, in blue) presents these 15 items, with each row representing one evaluation criterion. The two columns display the average scores for faculty tutors and alumni mentors, respectively, as rated on a 5-point Likert scale. As a result, color intensity (shades of blue) indicates the level of agreement, with darker tones reflecting higher average scores within each role, rather than absolute comparison across columns. This visual representation makes it easier to identify where perceptions of tutor and mentor support diverged most significantly. Upon reviewing the selected items, several recurring themes emerged – such as communication clarity, team motivation, emotional support, and resource guidance – which help frame the differing contributions of each role.

The standard deviation heatmap (Figure 3, in orange) adds another layer to the analysis by highlighting the consistency of student answers across the 15 evaluation items. While most evaluations were generally positive, student ratings showed more variation in some points for both tutors and mentors. The lower values indicate more agreement among students, suggesting a shared support experience, whereas higher values point to more varied opinions among students. This visual representation helps identify which aspects of tutor or mentor support were experienced consistently by most students and which may have been perceived differently across teams – possibly due to individual engagement, communication style, or student expectations about each role.

Among all the evaluation items, only one was rated higher for tutors than for mentors: "*The tutor discusses the results of the peer assessments with the team.*" This likely reflects the more formal role that tutors play in coordinating and supporting the peer evaluation process within the academic framework.

Creates a safe environment for sharing ideas	4.18	4.87	0.88	0.47
Clarifies doubts about PBL process	4.03	4.68	0.98	0.57
Supports the team in achieving goals	4.12	4.66	0.86	0.71
Shows concern for individual learning	3.88	4.39	0.82	0.95
Monitors balanced use of resources	3.97	4.47	1.10	1.06
Communicates clearly	4.24	4.74	0.83	0.60
Encourages critical analysis	4.06	4.55	0.97	0.55
Shows enthusiasm for the tutor role	4.00	4.47	1.12	0.83
Views students as responsible for their learning	4.24	4.71	0.75	0.57
Knows available project resources	4.09	4.55	0.80	0.69
Encourages individual study	3.79	4.24	0.86	1.00
Acts to energize team and report status	3.76	4.18	1.00	1.23
Encourages students to follow project plan	4.18	4.61	0.81	0.72
Helps refocus when team loses direction	4.03	4.45	1.05	0.86
Guides team when external info is needed	4.24	4.61	0.83	0.75
	Tutor Mean	Mentor Mean	Tutor SD	Mentor SD

Figure 3. Heatmap: Faculty Tutor vs. IEM alumni Mentor Evaluation (15 items with higher difference). Mean scores in blue, Standard Deviation in orange

To better understand how students saw the roles of tutors and mentors, their answers to the open-ended questions in the questionnaire were revised. Their comments gave valuable insight into what kind of support each role provided during the project. Table 2 summarizes these differences, highlighting how students described tutors' and mentors' focus, interaction style, and contributions - supported by short quotes in their own words.

Students tended to see tutors and mentors as having different yet complementary roles. Tutors were generally linked to academic support, especially in helping teams stay focused on learning goals and managing the project's structure. Conversely, mentors came across as more approachable and informal - someone the team could turn to for motivation, emotional support, and practical tips based on real experience. Both roles were appreciated and met different needs along the students' learning path.

During the focus group, a few students said they wished tutors and mentors had taken more initiative. That comment suggests that some may not fully understand the tutor's purpose. Rather than directing the project or providing solutions, tutors guide when asked and encourage students to take responsibility for their own learning. Even though this was explained at the beginning of the semester and reinforced along the way, not all students seemed to grasp it. It shows how important it is to set expectations clearly - and to return to them as the project progresses, especially in a learning model that places autonomy at the centre.

Table 2. Characteristics of the tutors and mentors reported by the students

Characteristics	Tutor	Mentor
Role and focus	Academic support especially related to peer assessment and guiding project structure. <i>"Gave feedback on peer evaluations and asked questions that made us think and research."</i>	Emotional and interpersonal support, especially in times of uncertainty. <i>"Guided us in more stressful moments."</i>
Academic support	Strong emphasis on helping clarify doubts and highlight essential aspects of the project. <i>"Clarified some doubts."</i> <i>"Helped us focus on what really matters and showed the value of teamwork."</i>	More related to report feedback, team management, and soft skills. <i>"Clarified doubts, especially about teamwork and presentations."</i>
Type of interaction	Structured and academically oriented. <i>"Helped interpret the peer assessment process."</i>	Informal, peer-level, and highly accessible. <i>"Helped the team stay united."</i>
Qualifications	Faculty members with subject expertise and project oversight roles. <i>"Having someone with experience to help us"</i>	Recent graduates with first-hand experience in PBL and professional insights. <i>"He helped us to be more organized and improve our relationships between members. He also provided us with tools that contributed greatly to the project."</i>
Goal of the relationship	To guide students in applying academic knowledge and managing learning processes. <i>"Keep the assessment in order as well as the delivery deadlines"</i>	To support students' integration into project work and university life, and offer motivational input. <i>"Give his perspective from when he was in our shoes."</i>
Goal	Help students progress academically through structured feedback and learning autonomy. <i>"The tutor showed interest in the good functioning of the team, in the distribution of tasks and in the team's commitment to the project."</i>	Foster a positive team dynamic and provide practical tips drawn from personal experience. <i>"The detailed information he provided us when we had questions and the feedback on the work the team was doing."</i>

5 Tutors and mentors perspectives: tutoring experience

This section shares what tutors and mentors said about their experience during the project. Their answers to the questionnaire help to understand how they felt in their role and how they viewed the students' involvement. Thus, this section intends to answer the question research 3: "How was the tutoring/mentoring experience?".

The tutors rated this tutoring experience with an average of 3.5 out of 5 points. Regarding the overall experience, the following main aspects emerged: (1) on the positive side, some tutors highlighted the opportunity to interact with students from the first year; and (2) on the negative side, complaints that the students had small interaction with the tutors and does not worked as a team. When looking at tutor's answers about how the students saw their role, 4 out of 6 tutors considered that students saw them as someone who could help them with technical content, something that it is not expected to occur. Surprisingly, only one tutor considered that the team saw her/him as someone more experienced that could help them with the project planning and management and another tutor mentioned that the team saw him/her as a team member.

In general, tutors and mentors considered this an easy task (average rate 4 and 3.75 out of 5 points to the question "Do you consider that being a tutor was an easy task?"). They also considered the teams were proactive (4 out of 6 tutors), not waiting for them replies to proceed in the project. In addition, they considered

the majority of the team members had a responsible attitude toward the project development and were motivated during its development (5 out of 6 tutors). This was not always the case, and for example, regarding the G5 tutoring (score 5.5), both tutor and mentor observed little proactivity and low synergy among the various group members. In the open-ended questions, some confusion was noted regarding the role of the tutors within the team - a student had expectations for the tutor that did not align with their role.

Furthermore, the six tutors that answered to the questionnaire showed that they were available to meet with the teams whenever necessary. They also considered that they supported the team in providing feedback when asked/required (5 out of 6 tutors). They also considered that stimulated their active participation (5 out of 6 tutors), incentivizing the team to research and analyse information about the project (4 out of 6 tutors). In addition, they considered that stimulated their autonomy (3 out of 6 tutors), helping them to distinguish the essential from the accessory (2 out of 6 tutors), helping to comply with the project plans and objectives (1 out of the 6 tutors) and sharing ideas and contacts (1 out of 6 tutors).

6 Conclusions

PBL has gained increasing recognition as an effective pedagogical approach in higher education, particularly within the field of IEM. In the context of IEM, where the application of theory to practice is essential, PBL offers students the opportunity to engage in real-world problem solving, collaboration, and hands-on learning. However, the success of PBL is not solely dependent on the design of the projects themselves but also on the support provided to students throughout the process. One of the key components of effective PBL is the role of tutoring and mentoring, which helps to guide students through complex tasks, foster critical thinking, and enhance learning outcomes.

This paper presents the results of a research on the impact of tutoring and mentoring on the success of freshman students in an IEM program during a PBL course. The study explores the approaches in which structured support systems, involving both peer mentoring and faculty tutoring can influence the learning experiences and academic performance of students engaged in project-based activities. By analysing the results of the questionnaires, it was identified some of the benefits: the opportunity to interact with students from the first year. In addition, some challenges were identified, namely, lack of involvement from the students and lack of ability to work as a team, and key success factors, availability for the tutors to meet with the students when necessary.

The tutoring experience allowed for the observation of significant student progress over the course of a semester, from their entry into university. Confidence, teamwork, conflict management, accountability, and public speaking were among the many aspects that improved. Growth was evident both on a personal level and as a team.

Through this study, it was sought to contribute to the growing body of literature on the effectiveness of tutoring and mentoring in PBL, offering insights into how such interventions can enhance student engagement, skill development, and overall educational outcomes. The findings provide valuable information for educators and institutions seeking to improve the learning environment for students entering the field of Industrial Engineering and Management.

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Experiences and recollections with Generative AI in Introductory Programming: A Case Study

Montse Farreras¹

¹ Universitat Politècnica de Catalunya, UPCBarcelonaTech, Barcelona, Spain

Email: montserrat.farreras@upc.edu

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Abstract

GenAI is here to stay, making it essential to prepare and support students in its effective use. Like most innovations, it brings both opportunities and challenges. GenAI has quickly become a versatile tool across domains—from creative writing to complex problem-solving—with programming emerging as one of its most transformative applications. These models offer not only code solutions and inspiration but also instant, iterative feedback, positioning them as powerful tools for skill development. This paper aims to review current literature and present a case study on the use of GenAI in an introductory programming course, assessing whether and how GenAI should support learning. We share findings and propose strategies for integrating these tools into educational settings while preserving the depth and integrity of student learning.

Keywords: Active Learning; Engineering Education; Artificial Intelligence; Project Approaches.

1 Introduction

The emergence and rapid proliferation of Generative Artificial Intelligence (GenAI), particularly Large Language Models (LLMs), mark a significant technological inflection point with profound implications across numerous sectors. As AI technologies continue to evolve and permeate various aspects of engineering practice, there is a growing need to reassess and adapt traditional educational paradigms to prepare future engineers for an AI-driven world.

Generative AI (GenAI) refers to a class of artificial intelligence models capable of producing text, code, images, and other forms of media in response to user prompts. Tools like OpenAI's ChatGPT⁴, Google's Gemini⁵, DeepSeek⁶ and GitHub Copilot⁷ are trained on extensive datasets and are able to generate highly coherent, human-like outputs. These capabilities make GenAI valuable for a wide range of tasks, including content creation, problem-solving, and decision-making. By enabling users to quickly draft documents, improve written work, and access information effortlessly, these tools are reshaping productivity and how we work and learn.

In educational settings, GenAI functions as an endlessly patient and always-available tutor. It delivers explanations adapted to individual learners' levels, assists in brainstorming, and offers real-time feedback—supporting a highly personalized and self-directed learning experience. Therefore, in recent years, GenAI tools are being explored for their potential to enhance learning environments, foster innovation, and prepare students for a digitally transformed future. (Dwivedi et al., 2021; Su & Yang, (2023); Noroozi et al. (2024)).

In engineering education, students have quickly embraced GenAI tools, especially those geared toward programming (Becker (2023)). Introductory programming courses, often serving as foundational pillars within engineering and computer science curricula, find themselves at the epicenter of this technological disruption.

⁴ <https://chat.openai.com>

⁵ <https://gemini.google.com>

⁶ <https://chat.deepseek.com/>

⁷ <https://github.com/features/copilot>

GenAI models exhibit striking proficiency in tasks central to these courses, including generating syntactically and logically plausible code solutions that can rival student performance, explaining complex programming concepts and code snippets, significantly enhancing the clarity and helpfulness of compiler error messages, and even simulating interactions akin to human tutors or teaching assistants. These tools are transforming how students engage with programming, often surpassing traditional methods that rely on static documentation, textbooks, or delayed instructor feedback (Yilmaz et al. (2023)).

The research community views GenAI as a potentially transformative force in education (Alasadi & Baiz (2023)), offering solutions to challenges like scalability and personalized feedback. However, ChatGPT, a cutting-edge natural language processing (NLP) model developed by OpenAI in 2019 (Lund & Wang, (2023)) was only released in late 2022. We are still in the early stages of understanding how to effectively integrate them into academic settings. Questions remain around when, how, and to what extent these tools should be incorporated into coursework and curricula and research around the topic has grown exponentially in the last years (Qadir (2023); Giannakos et al. (2024)).

In this context, this paper examines the capabilities and challenges of GenAI in a Python Introductory Programming Seminar, with the objective to assess whether and how GenAI should support learning. The methodology includes a narrative literature review and a case study. Specifically, the paper makes the following contributions:

- A state-of-the-art academic literature review of GenAI adoption and application into introductory programming education; identifying emerging pedagogical trends and adaptations, and key opportunities and challenges highlighted by researchers and educators.
- A case study analyzing students' experiences with GenAI, evaluating feedback and performance outcomes.
- An assessment of GenAI's impact on learning, aligned with Bofill's (2022) five-phase framework (motivation, information retrieval, understanding, practice, and feedback).
- Best practice guidelines and future research directions to accompany GenAI integration in programming educational settings.

The rest of the paper is organized as follows: Section 2 presents a comprehensive overview of the documented landscape regarding GenAI adoption into introductory programming education; This review establishes a crucial context for the subsequent case study; section 3 presents the GenAI assisted Python programming seminar; section 4 evaluates the seminar outcome; section 5 presents an assessment of GenAI's impact on learning and provides a best practices guidelines; concluding remarks are written in section 6.

2 The Current Landscape of GenAI in Introductory Programming Education

The period following the public release of powerful GenAI tools like ChatGPT in late 2022 has been characterized by rapid and widespread adoption, particularly among students. It has been necessary to understand these tools and explore their potential to build an *"Innovative pathway: Bridging Professional Development and Active learning"* (conference topic) to prepare students for a digitally transformed future.

Research indicates a high uptake of these tools in educational settings, specially in introductory programming courses (Becker et al (2023)). Surveys and usage tracking studies reveal that a significant proportion of students utilize GenAI for their academic work, sometimes irrespective of whether these tools are formally integrated into the course structure by instructors (Prather et al (2024)). Student perception surveys often report that AI systems are found helpful for academic tasks, although students also demonstrate awareness of the technology's limitations (Keuning et al (2024)) . However, usage patterns exhibit considerable variability.

Observational studies and analyses of interaction logs show that student engagement ranges from seeking occasional clarification or debugging assistance to heavy reliance on GenAI for generating entire solutions (Kazemitabaar et al (2023)).

The toolbox available to students and educators is diverse and expanding rapidly. General-purpose LLMs, most notably OpenAI's ChatGPT¹, remain widely used due to their accessibility and broad capabilities. Code-specific assistants integrated into development environments, such as GitHub Copilot⁴, are also prevalent, offering real-time code suggestions and completion. Increasingly, other powerful models like Google's Gemini² and Anthropic's Claude⁸ are entering the landscape, each with slightly different strengths and interfaces.

Within the specific context of introductory programming education, the literature highlights several dominant applications of these GenAI tools (Denny et. al (2024)):

- **Code Generation/Completion:** Generating code from descriptions, from snippets to full solutions.
- **Code Explanation/Comprehension:** Understanding code snippets, logic, or concepts.
- **Debugging/Error Message Enhancement:** Identifying errors and translating cryptic compiler messages.
- **Tutoring/Help-Seeking:** Providing on-demand, interactive assistance 24/7, like a personalized TA.
- **Broader Learning Support:** Understanding assignments, finding APIs, generating practice exercises, exploring alternatives.

Case studies illustrate these uses: Specialized tutors like RAGMan (Ma et al (2024)) and CS-Discuss (Yoonseok (2025)) use techniques like Retrieval-Augmented Generation (RAG) and guardrails for tailored, safe guidance, reporting positive student feedback and engagement. Other examples include chatbots for domain-specific activities, specific simulations (Liang (2023)) and practice environments like Codecademy's simulators (Hashmi et al (2024)). Observational studies reveal diverse interaction patterns, including concerning ones like submitting entire problems to AI without prior effort and infrequent verification of AI solutions (Amoozadeh (2024)). Comparative studies show mixed results on learning outcomes, with some reporting increased interest (Alpizar (2025), Llerena et al (2024)) and others finding no significant performance difference but reduced use of traditional resources (Yuankai et al (2024)).

The focus in computing education is shifting from debating GenAI's permissibility to developing strategies for safe and effective integration that supports learning. There's a noticeable trend from using general tools towards developing specialized educational AI systems with pedagogical safeguards (Vidalis et al (2024)) and to personalized and adaptive learning tailoring content, difficulty, and feedback at scale (Onyebuchi et al (2025)). While, another trend gears towards is explicitly teaching AI collaboration skills (Denny et al (2024)).

2.1 The Research Perspective: promises and pitfalls of GenAI

Integrating GenAI into introductory programming education presents substantial opportunities, including personalized learning at scale, increased engagement, and 24/7 support that enhances accessibility - especially in large classes. It boosts student motivation, autonomy, and confidence while preparing them for the AI-driven workforce. Additionally, it enables students to progress more quickly and tackle complex challenges earlier. However, if not carefully guided, the ease of assistance could undermine deep learning by minimizing the productive struggle essential for long-term understanding (Yilmaz et al, 2023; Prather, 2024; Alasadi & Baiz, 2023).

While AI can greatly enhance productivity, some educators express significant concerns sometimes viewing the technology with caution or skepticism (Mittal et al. (2024); Sharples (2023)). Notably the risk of over-reliance

⁸ <https://claude.ai/>

that can hinder skill development and negatively impact learning, particularly among lower-performing students. It also raises concerns about academic integrity, as AI-generated code complicates assessment validity in unsupervised settings. Ethical issues include bias in AI outputs, unequal access, privacy risks, lack of transparency, and intellectual property concerns.

Moreover, practical barriers such as AI inaccuracy, infrastructure costs, faculty training needs, and curriculum redesign further complicate implementation. These challenges are deeply interconnected, requiring a holistic approach that combines thoughtful assessment reform and pedagogical innovation.

3 The AI-assisted Python Programming Seminar

We studied the impact of GenAI usage in a 20-hour introductory Python course aimed at students with prior experience in languages like C or Java. The course followed a problem-based, game-driven approach rather than traditional lectures. Its core was an escape room game where students solved programming challenges (e.g., Morse decoder, turtle graphics, number converters) to unlock clues, blending fun with serious learning. Game elements enhanced motivation, while embedded hints in the course notes encouraged engagement with the material. The escape room covered 10 hours; the remaining time focused on team-based programming projects to foster collaboration and practical application (Bofill 2022).

In this edition, students were directed to recommended IDEs and GenAI tools for development. The course, along with supporting materials and usage guidelines for GenAI, was structured as follows:

1. **To start:** Students were introduced to the course and asked to complete a questionnaire to set expectations and reflect on their current AI tool usage. They received Python notebooks with simple code examples to illustrate syntax, using Google Colab for experimentation. ChatGPT was recommended for clarifying explanations and deepening understanding.
2. **To continue- The escape room:** A escape room was designed to maintain challenge and avoid trivialization, emphasizing that the game's goal was learning (Bofill 2022). Challenges included a Morse decoder, a recursive Hanoi Tower visual using turtle graphics, a hex-to-decimal converter, and a system-of-equations solver using the Gauss-Jordan method. Templates were provided to guide students in Object-Oriented Programming and to limit overreliance on GenAI by requiring students to understand and adapt code, rather than copying it blindly.
3. For students already familiar with programming, mastering Python syntax is relatively easy (learning phase 3 (Bofill (2022))). The real challenge lies in applying this knowledge to problem-solving (learning phase 4). A passive, lecture-based approach to teaching syntax would be unengaging. Since programming is a skill, it must be developed through practice.
4. **To live- The personal project:** In this part of the course the students are asked to work on a project of their own interest and they are encouraged to use AI freely as they like for brainstorming, developing and debugging.
5. **To rest:** At the course's end, students completed a feedback questionnaire reflecting on their learning outcomes, the course experience, and their use of GenAI throughout.

4 AI-Assisted Course Evaluation

To evaluate the activity and enhance future editions, we developed a questionnaire based on the standardized Student Evaluation of Educational Quality (SEEQ) instrument, which includes both closed and open-ended questions. Table 1 presents the questions specifically related to the use of GenAI. Students were asked to complete two questionnaires: one before the course and another after its completion. The first two questions in Table 1 (italicized) address GenAI usage prior to the seminar, while the remaining questions were answered afterward.

Table 1. Summary of the questionnaire based on SEEQ regarding the use of GenAI tools

	Statement	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1	<i>I usually use GenAI for my studies</i>	1	2	3	4	5
2	<i>For what purpose do you use GenAI in your studies?</i>	<i>For all I can</i>	<i>To solve the assignments</i>	<i>For programming</i>	<i>To study (feedback)</i>	<i>I do not use it</i>
3	For this seminar: the use of GenAI tools has helped me to solve the challenges	1	2	3	4	5
4	The use of GenAI has helped me to acquire a deeper level of understanding	1	2	3	4	5
5	Using GenAI increases my motivation because I make faster progress and do not get stuck	1	2	3	4	5
6	Besides the seminar documentation what other sources have you used?	GenAI	Official libraries documentation	Youtube videos	Google	Others
7	Explain your experience using the GenAI tools					
8	What is your favorite GenAI?					

4.1 Questionnaire results analysis

This section analyzes the results based on the students answers to the questionnaire.

Regarding the two preliminary questions about GenAI use: Question: "I usually use GenAI for my studies" was answered with a unanimous "Strongly agree" and Figure 1 left shows the distribution of purposes (answering question 2). Figure 1 right shows the favorite GenAI tool obtained compiling results from question 8.

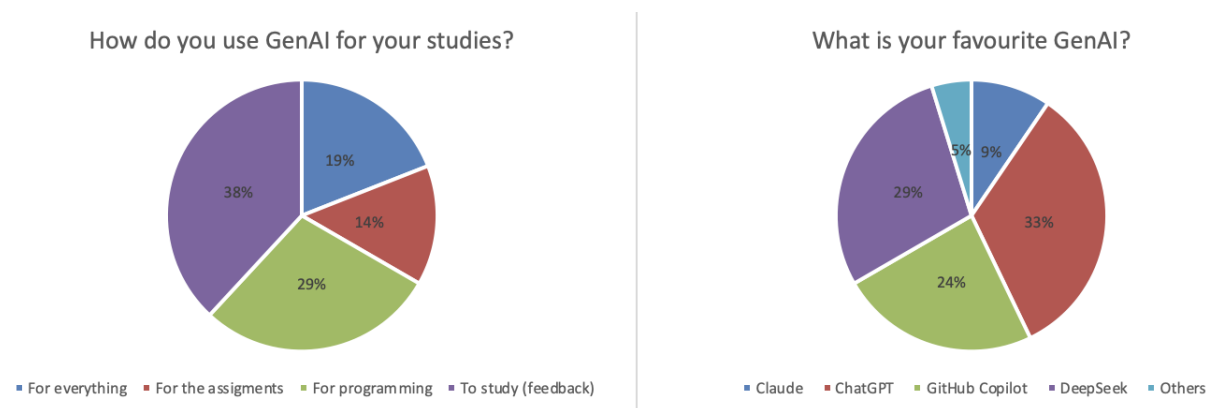


Figure 1. Feedback display on the GenAI purpose (left) and favorite model (right)

To add value to the GenAI assessment, GenAI tools have been used here to analyze the results presented in Figure 1. When prompted with the Figure ChatGPT answer: "Looking at both charts in Figure 1 together reveals a clear picture of GenAI usage among students. The data shows that while GenAI is used across multiple academic activities, it's predominantly leveraged for study feedback (38%) and programming assistance (29%), with fewer students using it for assignments (14%) or as an all-purpose tool (19%). This usage pattern aligns with their tool preferences, where ChatGPT (33%) and DeepSeek (29%) together capture the majority of user preference, followed by the programming-specific GitHub Copilot (24%)"⁹

⁹ In this analysis, an interesting observation emerged: while ChatGPT provided the correct answer, the Claude model confused itself (Claude) with DeepSeek, incorrectly stating that Claude was one of the students' preferred tools

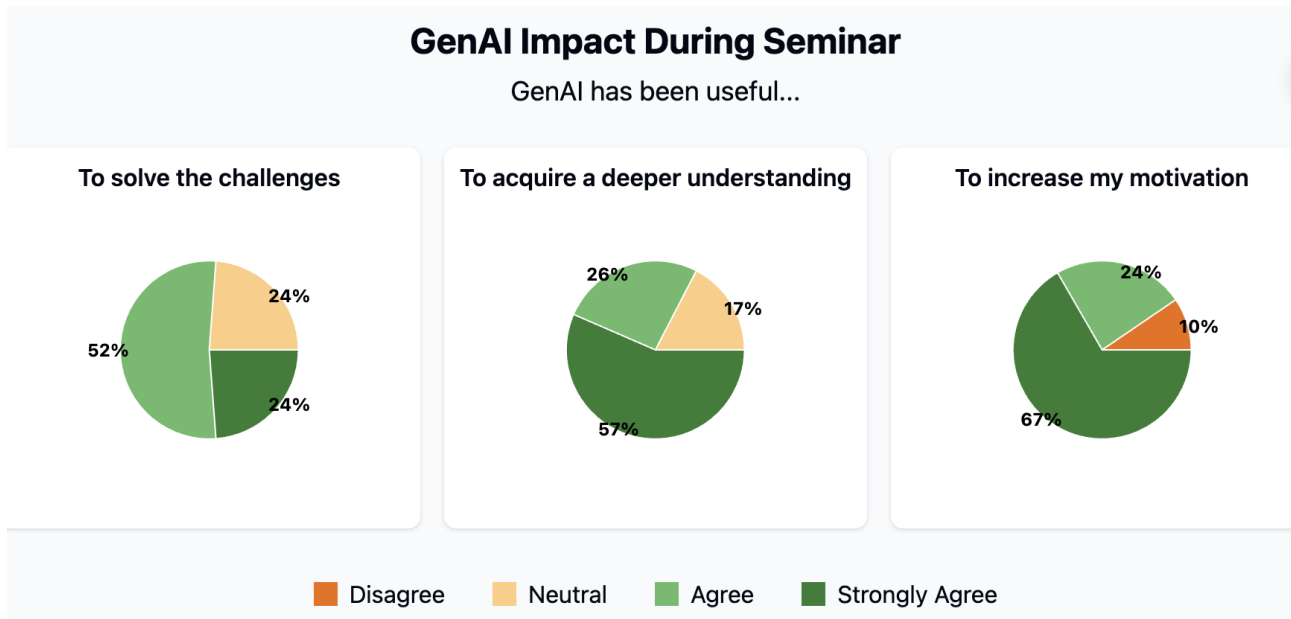


Figure 2. Feedback display on the GenAI usability during the seminar.

The data in Figure 2 (coming from questions 3,4,5) shows very positive reception overall, with the strongest positive impact being on motivation, followed by deeper understanding and then problem-solving.

Figure 3 reflects students answers to questions 6 and 7. Overall, Figure 3 charts reveal that participants heavily relied on internet resources and specifically GenAI tools for documentation, with official documentation used much less frequently. For GenAI applications specifically, explanation capabilities were most highly valued, followed by search functionality and brainstorming assistance. This suggests GenAI is particularly effective as an educational tool that helps participants understand concepts rather than just as a practical coding utility (Claude Generated).

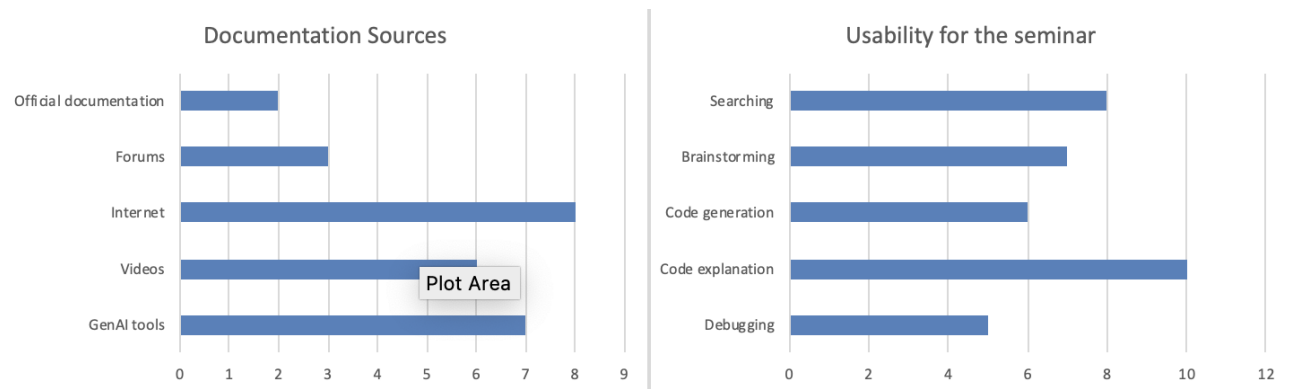


Figure 3. Feedback display on documentation sources (left) and usability of GenAI models to carry on with the Python programming seminar (right).

4.2 Further analysis based on students' feedback and performance

Based on selected comments from students regarding their experience with GenAI tools, they showed awareness of GenAI limitations in terms of accuracy, reliability and potential "hallucinations" (generating incorrect or false information). In their words: *"For small examples it was good but not for bigger programs,"* *"Useful, but you need to know how to use it."* or *"It does not solve your problems but it helps"*. They particularly appreciated its help with syntax correction, code snippets, and identifying the right libraries: *"Python has a lot of libraries—ChatGPT helped me quickly find the one I needed and how to use it."*

Others described GenAI as a patient tutor that provides timely feedback and explanations: *"It helped me a lot to understand code snippets and the language itself."*

Considering students' performance, a notable outcome of introducing GenAI into the Python programming seminar was the increased complexity of the personal projects chosen by students. A qualitative comparison reveals that, in this edition of the course (where the use of GenAI tools was encouraged), students opted for more ambitious projects—for example, a music media player, a chatbot with LLMs that plays musical notes and chords, a role-playing game, a tool to plot real-time sensor temperature, a plant recognition model, a turtle-based drawing app etc...

This contrasts with the previous year, when students—without GenAI support—tended to choose simpler projects suggested by the instructor, such as card games, a snake game, a basic drawing program limited to circles, a simple encryption algorithm, or a to-do list app.

These results highlight both an increase in student motivation and the productivity gains enabled by GenAI tools. At the same time there is a recognition of risks and limitations.

4.3 One more experiment

GenAI tools are proving to be extremely effective as code assistants—but where is the limit? These tools can solve complete assignments from an introductory Python programming course. For example, GitHub Copilot successfully completed the Tower of Hanoi problem—a classic recursion exercise—by interpreting the comments within a provided code template, generating functional code, and even animating the solution using Turtle graphics.

To further explore the tool's capabilities, we tried a more ambitious prompt: *"Please write me a program with similar functionality to Microsoft Word."* The response was: *"Creating a full-featured word processor like Microsoft Word is an enormous task—Microsoft Word is the result of decades of development, with thousands of features including rich text formatting, (...). But I can absolutely help you build a simplified version (...). Here's a basic rich text editor in Python using tkinter: (...)"*

After providing the initial code and explanations, the tool continued: *"What new features would you like to add—support for images, spellcheck...? I can expand the version step by step for you!"*

In theory, with enough patience and iterative prompting, one could gradually reach the original goal. In practice, however, the process might be more time-consuming and frustrating than simply coding it from scratch.

5 Recollections and guidelines

GenAI is no longer a future prospect but a present reality. Its integration into educational settings is essential for workforce preparation and AI literacy, equipping students with industry-relevant skills. Based on the observations in our Case Study, we present an assessment of GenAI's impact on learning, aligned with Bofill's (2022) five-phase framework ((1)motivation, (2)information retrieval, (3)understanding, (4)practice, and (5)feedback). The following benefits have been identified:

1. Increased student engagement and motivation, necessary precursor to any learning (phase 1).
2. Enhanced self-efficacy, contributing to deeper understanding and accelerated learning (phases 4 and 5).
3. Improved information access, with students effectively using GenAI as an intelligent search engine (phase 2).

4. Appreciation for 24/7 AI tutoring (phase 3), offering personalized and timely feedback, supporting phases 4 and 5 by making learning more interactive and reducing frustration while promoting autonomy and confidence.

Overall, we conclude that GenAI effectively supported all stages of the learning process: motivation, information retrieval, understanding, application, and validation; enhancing students learning.

Concerns regarding GenAI's reliability and potential for "hallucinations" can be mitigated through appropriate usage. Best practice strategies may include:

1. Raising student awareness of risks and limitations (in this course, students quickly identified them);
2. Gradually integrating GenAI with prompt iteration and continuous frequent testing;
3. Verifying AI-generated content against official documentation;
4. Using GenAI as a collaborative assistant rather than a source of final answers;
5. Reinforcing foundational knowledge through manual coding practice.

Institutional barriers must first be addressed through instructor training and the development of best practice guidelines for effective GenAI use. These practices should then be communicated to students to ensure meaningful integration.

Finally, academic integrity and assessment validity—highlighted in the literature—call for assessment reform that should shift responsibility for learning back to students, grounded in the trust that they are intrinsically motivated to learn. Ethical considerations surrounding GenAI, while significant, are beyond the scope of this paper.

6 Conclusions

GenAI is here to stay, making it essential to prepare and support students in its effective use. Like most innovations, it presents both opportunities and challenges.

The benefits are well documented: enhanced personalized learning, prompt feedback, improved information accessibility, and increased student engagement, motivation, self-efficacy, and autonomy. Moreover, these advantages scale across large student cohorts and offer significant potential for accelerated learning and deeper understanding by supporting a highly personalized and self-directed learning experience.

To tackle the challenges, it is crucial to first overcome implementation barriers by training instructors, redesigning curricula, establishing and disseminating best practice guidelines, and reforming assessment methods to restore the responsibility of learning to students.

Beyond education, GenAI's greatest practical utility as a coding assistant may lie in its function as an intelligent search engine—guiding users toward relevant libraries or solution strategies and thereby improving productivity.

A widespread concern involves long-term over-reliance on AI tools, potentially undermining fundamental learning. However, this can be mitigated by recognizing that we are entering a new era of programming. Looking ahead, two scenarios may unfold: in one, we design and develop software using natural language through iterative prompting, potentially lagging behind traditional coding in efficiency; in the other, the inherent imprecision of natural language may reaffirm the need for formal code, leading us back to current practices.

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Human flourishing and social service in engineering students

Gerardo Salvador Gonzalez Lara¹, Arturo Rodriguez Rodriguez², Raul Carlos Verduzco Garza³

¹Department of Humanistic Studies, School of Humanities and Education, Campus Monterrey, Tecnológico de Monterrey, Mexico.

²Department of Social Service, Campus Monterrey, Tecnológico de Monterrey, Mexico

³Associate Director of Department of Humanistic Studies, School of Humanities and Education, Campus Monterrey, Tecnológico de Monterrey, Mexico.

Email: gsgonzal@tec.mx, arturo_rdz@tec.mx, raul.verduzco@tec.mx

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Abstract

It is imperative to design innovative interdisciplinary didactics for engineering students as a way to: 1) the contribution of this valuable talent to social service during all stages of university education and, 2) stimulate human flourishing as an indispensable element from their youth for personal and professional development by improving the lives of others. Tec de Monterrey's Educational Model is based on disciplinary and transversal competencies, and on Challenge-Based Learning. The training unit called *Semana Tec con sentido humano* "*El rol de mi profesión el desempeño de mi profesión*" y "*Construcción de comunidades inclusivas a través de la dignidad humana*" (Tec Week with Human Sense: The role of integrity in the performance of my profession and Building Inclusive Communities from Human Dignity). was designed with eight hours of daily activity for weeks 6/18 and 12/18 of the semester. Students collaborate in an interdisciplinary manner at least twice during their university life in the concrete solution of a social problem to develop the competency Ethical and civic commitment in the sub-competencies: a) Integrity, and b) Recognition and empathy. With the accompaniment and guidance of the professor, and the training partner -a public or private instance- with a need. This Tec Week is integrated with theoretical frameworks and current indicators on human dignity, ethics, legality, transparency, diversity and inclusion, corruption, among others. Through a dialogue with the training partner about its mission and service, and direct immersion in the problem to be solved, engineering students design prototypes that are implemented. The evaluation of the development of transversal competencies in students is conducted by the professor. Since 2019, in the 32 campuses of Tec de Monterrey there are approximately 1000 groups in Tec Weeks with Human Sense with approximately 5000 prototypes. This article for PAAE/ALE 2025 presents the theoretical foundation of Human Flourishing, the didactic design, types of training partners and recent examples of prototypes of the authors.

Keywords: Interdisciplinarity, human flourishing, social service, transversal competencies.

1 Introduction

Engineering education must offer innovative paths that connect professional development and active learning not only in the specialized knowledge of engineering, but with equal importance, with the development of transversal ethical and citizenship competencies. That is why it must be ensured that the teaching/learning process is a solid bridge that connects the needs of society with the solutions that can be provided by the various engineering disciplines through ethical training throughout professional education. For this purpose, it is necessary that within the universities, the objective is to establish a close relationship with a permanent dialogue between different instances and academic departments with didactic projects that manage to potentiate the formative sense of each one of them in the integral profile of the students. This objective will be achieved through the interdisciplinary design of innovative didactic models and techniques that manage to build in a complete way the professional and formative profile that today is needed from future graduates. This is the case of the present work in which the Department of Humanistic Studies, the Department of Social Service and all 18 engineering careers of the Monterrey Campus are united in the same project: Tec Week with Human Sense: Building Inclusive Communities from human dignity.

The present work proposes as a research assumption:

"Students of engineering careers discover their human flourishing from their university stage when performing a social service with the didactic design of the *"Semana Tec son sentido humano: construcción de comunidades inclusivas desde la dignidad humana"* (Tec Week with Human Sense: Building Inclusive Communities from Human Dignity), and, simultaneously, develop the transversal competence of recognition and empathy; both elements will shape their professional profile when they join the working world with their professional degree".

The following objectives:

General objective: To evidence that human flourishing can be discovered by engineering students from their university life through social service.

Specific objectives:

- 1) Explain the didactic model of the Tec Week are human sense.
- 2) Justify why human flourishing and ethics of professions in social service are simultaneous formative components in engineering students when performing social service with this didactic model.
- 3) Demonstrate examples of prototypes that provide solutions to social problems as a result this social service.

It should be noted that the team of authors of this work, in addition to their teaching, administrative and research work, are part of the academic and administrative team that manages the *Semana Tec con Sentido Humano* (Tec Week with Human Sense) at the Monterrey Campus.

The Department of Humanistic Studies is assigned for scheduling groups, ensuring the accreditation and training of professors of this academic department to each group, assigning classrooms and schedules, providing didactic platforms for interaction, recording grades and hours of social services.

The Social Service Department has contact with the public or private non-profit organizations with which it will work, identifies their needs, designs the Canvas platform for the development of the course, the work agenda, theoretical content, didactic activities and quantitative and qualitative evaluation rubrics, before and after meetings with assigned professors, allocation of social service hours and follow-up on the implementation of the final projects, among other aspects.

Students from the 18 faculties of the School of Engineering register for the *"Semana Tec con Sentido Humano: Construcción de comunidades inclusivas desde la dignidad humana"*.

2 Development

Tec de Monterrey's Educational Model is based on challenges (Tec de Monterrey 2016). The academic periods of Tecnológico de Monterrey in professional careers are made up of semesters that run from February to June, and from August to December; there are intensive winter courses in January, and summer courses in the month of July. The semesters are organized in 18 weeks, which are numbered from 1 to 18 for scheduling purposes. During weeks 6 and 12 of the semester students must take a Tec Week.

What is Tec Week? The Tec Week consists of an immersion of professional career students to conduct a challenge for the development of competencies that meet a need of the training partner in only five days. It is a period of five days equivalent to 8 units or hours of work each day, totaling 40 academic units or credits to develop specialty competencies or transversal competencies. The student can choose from a catalog of weeks but is obliged to take two Tec Weeks called "Tec Weeks with human sense" during his career.

And what is a Tec Week with human sense?

A Tec Week with Human Sense has the objective of developing the transversal competency Recognition and Empathy. By taking it, students collaborate in the concrete attention of a social problem, develop disciplinary and transversal competencies, with the accompaniment and punctual guidance of professors and training partners (Tapia 2021).

The training partner is a non-profit organization or body, public or private, that expresses one or more needs that the students could solve with the knowledge acquired so far in their professional career, and makes an agreement with Tec de Monterrey for which the students design a prototype or project for its solution.

Each Tec Week includes an agenda for reading and understanding theoretical frameworks related to the respective training purpose, spaces for at least two classroom dialogues or immersion in work field and moments for the design of the prototype or project according to the SlowU didactic methodology, which is a work culture that promotes values and practices with which we take the time to really understand social problems and from the collaborative, horizontal, inclusive and open work; effective proposals are designed to address a social need. For this, the methodology is guided by listening devices: unlearning, mapping and documentation with a field notebook, dialogue guides with the training partner for the projects and final proposal (Lafuente 2020) to finish with the delivery to the training partner of a prototype or final project. In each group of 35 students, groups of three to five students are integrated for their prototypes (Lafuente 2023). The Tec Week with human sense: building inclusive communities from human dignity aims to develop the transversal competence Recognition and Empathy which is defined as:

Respect the dignity, rights, contributions, personal circumstances and those of others, seeking to present constructive and supportive solutions to other people's situations.

Tec de Monterrey defines it as follows:

Respect the dignity, rights, contributions and personal circumstances and those of others, seeking to present constructive and supportive solutions to other people's situations. At this level, greater emphasis is placed on the second type of situation. To do the above, knowledge related to human dignity, empathy, human rights and sustainable development goals are mobilized; elements of the social, political, economic, cultural and environmental context are considered, as well as the development of the life project and the analysis of qualitative and quantitative information (Tec de Monterrey 2016). (Tec de Monterrey 2016).

The Tec Week: building inclusive communities based on human dignity was implemented at the Monterrey Campus and the rest of the Tecnológico de Monterrey campuses nationwide since August 2020.

The present work covers a demonstration that covers the periods from Aug-Dec 2022 to Feb-April 2025, totaling 13 Tec Weeks over six semesters where students at the School of Engineering apply their knowledge to concrete solutions to social problems. Based on this didactic model, the Social Service area, together with the School of Engineering, has a system for the production and follow-up of prototypes that endorse the students' social service hours, a process that had no empirical evidence of its results.

2.1 Theoretical basis of the didactic model

The Tec de Monterrey Educational Model (2016) is based on the development of competencies and through challenge-based learning.

In this Model, competency is understood as the conscious integration of knowledge, skills, attitudes and values that allows successfully facing both structured and uncertain situations and that may involve higher order mental processes. Competency integrates both the knowledge and procedures of discipline, as well as the attitudes and values that allow the formation of participative professionals committed to society. In the TEC21 Educational Model there are two categories of competencies: discipline and transversal. Disciplinary competencies refer to all those knowledge, skills, attitudes and values that are considered necessary for professional practice. The development of disciplinary competencies implies a gradual construction that starts from the fundamental competencies to the terminal competencies of the discipline. On the other hand, transversal competencies are developed throughout the training process of any discipline, are useful for the graduate's life and have a direct impact on the quality of professional practice.

Challenge-Based Learning. In this same model, it is implemented through active learning from a Challenge-Based Learning approach, defined as: "It is a pedagogical approach that actively involves the student in a real, relevant and environmentally related problematic situation, which implies the definition of a challenge and the implementation of a solution. Challenge-based learning is based on experiential learning, which is based on the principle that students learn best when they actively participate in open learning experiences, rather than passively intervene in structured activities. In this sense, Experiential Learning offers students opportunities to apply what they learn in real situations, where they face problems, discover for themselves, try out solutions and interact with other students within a given context (Moore 2013). Experiential Learning is an integrative integrated approach to learning, combining experience, cognition and behavior (Akella 2010).

In this educational model, we agree with Francisco Ayala, who states that: "Along these lines, the professor's function is also that of an advisor who shows confidence and respect for the diverse possibilities of development of each of his students, which moves him to seek the most effective way for them to achieve integral development" (Ayala 2002).

The identification of the challenges for the development of transversal competencies and learning experiences is done through a dialogue between the teaching team and the representatives of a public or private entity called "Training Partner" about the needs that the students would help to solve. A protocol or Academic Collaboration Agreement is signed, with the previous authorization of the Academic Department Direction, and then the general objective and specific objectives are defined, both for students and professors.

2.2 Theoretical underpinnings of human flourishing

It is assumed that through Tec Week with Human Sense: Building communities from human dignity, engineering students stimulate human flourishing through social service in which they put together their talent and disciplinary knowledge acquired up to that moment to solve a real social problem and feel themselves active collaborators in the mission and objectives of the assigned training partner.

Generally, human flourishing is a concept associated with mature people, or university graduates, who discover it, aware that they are already at an age or period of their lives worthy of attention or discovery for better community living.

Is it possible to discover it from the university formation? To do something for others or for the community from the university formation? It is affirmed that yes, by means of the Social Service through the design of the Tec Week with human sense.

According to Tecnológico de Monterrey (2024), human flourishing:

It is a personal and conscious process of developing capacities in all areas of life, in which each person relates to the community and the environment to create a better world, respecting his or her own dignity and that of others... [even when carried out in community] the person is the center. It is a conscious process that responds to personal convictions, purpose and action. It is a process interrelated with the conditions of the social and environmental context.

The professor must be aware of his own human flourishing also stimulate it in his students integrated to the didactic processes within the university environment, which is to say, in the classroom or laboratory.

Therefore, the teaching activity should be complemented with the integration of cultural, cathartic and personal harmony aspects to be able to give oneself to others enjoying personal harmony in all senses.

2.3 Theoretical basis of Social Service in applied engineering ethics

What is intended for engineering students with Social Service (SS)? Why should SS be an opportunity for Applied Ethics? It is intended that students build and feel their own horizon of fulfillment and fulfillment within a framework of autonomy, and at the same time within the social and cultural groups to which they belong in the community. According to (Xteberria 2002), the Aristotelian Approach to ethics emphasizes the importance of the development of virtues, and affirms that the best way to learn virtues is through imitation; in universities, by tradition, professors are the model to imitate for young people, hence the importance of the teaching staff's active involvement in the SS. On the other hand, the Epicurean approach to ethics perceives as a purpose a decrease of pain and increase of pleasure among human beings, therefore, the healthiest thing is to create a pact of convenience among all, so that, as a group, and not individually, the least pain and the greatest pleasure for the most possible is achieved; that is why the SS aims to promote the collective good, rather than the particular. From a utilitarian approach, an ethical dilemma arises between considering a greater number of beneficiaries vs. a smaller number of non-beneficiaries, so that before a given act or decision, the dignity of all should always be respected equally, and not only favor a few people or cultural groups, leaving others discriminated from a benefit. By relating the three ethical approaches briefly mentioned with the students' SS, it will be possible to arrive directly at what Etxeberria calls a shared Happiness, that is, the one that arises at the moment in which the human being applies his own ethics and promotes for others and for himself that shared happiness, turning it into solidarity; solidarity of the student towards his environment and in this way it will be possible to move from daily experiences of SS to vital experiences of ethical internalization. In addition, it is possible for professors and educational institutions to get their students to make a moral reflection.

Social service in universities. In addition to the teaching of knowledge and values, it should be the duty of higher education institutions to promote through teaching the practice of those skills that prepare students to face various situations that require complex mental processes in their academic performance and later in the real world of building a professional career. In accordance with the Educational Model of Tecnológico de Monterrey, the Social Service promotes the practice of volunteering by students to fulfill their duties to society as professionals and citizens. This model was complemented with the approach of the Service Learning model proposed by the Polytechnic University of Valencia (2020) in which they state that: "Service

3 Implementation of Tec Week with human sense

As part of their training, students participate in the following didactic experiences, each with its own pedagogical model: Tec Week of Induction to Social Service, Tec Week with Human Sense with the following thematic areas: Integrity, Zero Hunger, Inclusive Communities, Climate Emergency, and Philanthropy. Other models with similar purposes, but with five weeks of duration are: Human Sense Block, Social Immersion, and Project Solidarity. For the purposes of this paper, only the *Semana Tec con Sentido Humano* will be addressed, specifically in the thematic area of inclusive communities. A Tec Week has a working duration of one week, which is offered in two moments within the semester periods and where students collaborate hand in hand with a professor and a civil society organization to address social causes related to the thematic area offered. The Tec Week with a focus on Inclusive Communities seeks to promote the development and recognition of human dignity to build safe and inclusive communities while promoting inclusion, gender equality and strengthening practices that benefit them.

To guarantee a good implementation of the Tec Week, there is a Tec Week agenda that is communicated to the students from the beginning as a crucial element in the Canvas electronic platform. Interaction with the training partner can be face-to-face or remotely via the zoom platform, teams or meet.



Figure 1. Work agenda of the *Semana Tec son sentido humano*.

The instances involved for this training unit are: The 18 academic departments of the School of Engineering, the Department of Humanistic Studies and the Department of Social Service. The theoretical frameworks of this Tec Week cover the following topics: 1. What does it mean to recognize human dignity? a) Why talk about human dignity. 2. Discover diversity: a) What are unconscious biases, b) Diversity and inclusion, and c) Gender perspective.

In August 2019, the implementation of the Tec21 Model began at Tecnológico del Monterrey. This model seeks to move from a traditionalist education-teaching to a new training based on learning challenges. This model, beyond only seeking to impact the professional training of students, also highlights the need for human sense within the new generations. Therefore, through the Social Service, it places the personal talent of each of the participants at the service of others.

Table 1. Below are indicators from the August-December 2022 semester to date of the interaction, information, results and progress that have been made in this Tec Week with human sense: Building inclusive communities based on human dignity.

Period	Week	Groups	Students	Prototypes	Focus on Engineering
August-December 2022	Week 6	3	113	19	0
	Week 12	2	43	8	2
February-June 2023	Week 6	6	176	36	6
	Week 12	5	142	28	3
August-December 2023	Week 6	7	213	78	10
	Week 12	9	217	32	4
February-June 2024	Week 6	19	494	99	18
	Week 12	15	376	83	17
August-December 2024	Week 6	4	120	26	5
	Week 12	3	65	14	1
February-June 2025	Week 6	14	422	47	5
	Week 12 *				
Totals:		87	2,381	470	71

*Week to be held from May 5 to May 9

Interpretation: There are 71 prototypes focused on the solution of a social problem from the careers of the School of Engineering; to validate their feasibility, the evaluation method consists of two moments: during the Tec Week, specifically in the collaborative spaces within the agenda entitled "moments of service" 1. Validation and start of prototype, and 2. Subsequently, the prototypes are delivered to the organizations for immediate implementation. And as the last part of the method, feedback or comments are received from the training partner on the implemented prototypes, and those that obtained the most outstanding results are identified.

The 41 participating organizations or training partners during the periods mentioned are listed below: ACNUR, ALZ Monterrey, ANSPAC, Asociación de Psicólogos de Nuevo León, AWAQ ONGD, Best Buddies de México A.C., CADHAC, Campamentos Tec Casa Hogar Refugio 121, Casanicolás, Centro de Entrenamiento Acuático, Ecoaldeas del Norte, Edumakers, Enseña por México, FICAE, FONDEAGG, Fundación El Mundo Escribe, Fundación Salvador Vida México, Género, ética y salud sexual AC, Inclusión Tec, Instituto Down, Instituto Nuevo Amanecer, Lazos que transforman, LGBTIQ WORLD, A.C., MAFI, Magis Fidem, A.C., Misión del Nayar, Oídos valientes PowerChair, Salud Mental para Indigentes A.C., Secretaría de Igualdad e Inclusión de Nuevo León, Sonrisas de Cristal, Soy Plena, Tutores de Resiliencia, UNAC, Unidos, Vercodi, Viccali, VIFAC, VIDUSA.

The following is a virtual resource where the 71 prototypes focused on the engineering area can be viewed, divided into a) the visualization of the prototype; and b) the documentation that is the theoretical support of the prototype.

As a sampling of these works, all equally important, we suggest identifying the following: *EdumakersRED*, *Inclusive Voices*, *Instructional Matching*, *R-ACNUR* and *Sustentrack*:

<https://drive.google.com/drive/folders/1Enc1mrVZsooqzJ3PXwH4R5cMfbOviUGQ?usp=sharing>

Table 2. Engineering students during the period Aug-Dec 2022 to Feb-April 2025.

Total students in <i>Semana Tec con sentido humano: Construcción de comunidades inclusivas desde la dignidad humana</i> (Tec Week with human sense: Building inclusive communities based on human dignity) in the indicated period.	Students at the School of Engineering	Percentage
2381	887	37.25%

Interpretation: The participation of students from the School of Engineering this Tec Week in engineering students is 37.25 percent.

The engineering careers most involved with these products are Data Science and Mathematics Engineering, Robotics and Digital Systems Engineering, Industrial and Systems Engineering, Mechatronics Engineering, Computer Technologies Engineering, Civil Engineering, Mechanical Engineering and Biomedical Engineering.

4 Evaluation of results

The initial research assumption was favorably verified: Students of engineering careers discover their human flourishing from their university stage when performing a social service with the didactic design of the "*Semana Tec con sentido humano: construcción de comunidades inclusivas desde la dignidad humana*", and, simultaneously, they develop the transversal competence of recognition and empathy; both elements will shape their professional profile when they enter the working world with their professional degree.

Student feedback. To learn about the students' experience within the Tec Weeks, a feedback survey was applied to the most recent Week the March 17-21, 2025, with the following result:

Universe: 1,987 participated in the survey, participation rate 56.94%.

62.46% mentioned that they became aware of the social needs of their community, the country and the world.

57.40% believe that their prototype/project will have a positive impact on today's society.

On a Likert scale where 5 is the highest and 1 is the lowest students were asked the following questions:

Satisfaction with the didactic design of the Tech Week: 49.86/5

Testimony of the training partner *Amigos de la Sierra*: "Thank you very much for the opportunity! It was an extraordinary experience; I enjoyed it very much... I hope we can continue collaborating" and the training partner *100enundía*: "Thank you very much for the invitation... The truth is that the experience was quite interesting, since the ideas of some of the students were creative and hit the nail on the head in what I was looking for".

5 Conclusions

Interdisciplinary work within universities is important for an educational and didactic project with the same objective. With the 71 prototypes of eight engineering schools in the states of Nuevo León, Chihuahua, and Mexico City in Mexico; and in Bogotá, Colombia, the research assumption was demonstrated and the general objective and the three specific objectives presented at the beginning of this work were achieved, thus validating and consolidating that the didactic design of the Tec Week with Human Sense: Construction of inclusive communications from human dignity stimulates human flourishing from the university life of future engineers developing the transversal competence Recognition and empathy within a horizon of plenitude by consciously making available to others their talent and knowledge for a shared happiness, a trait that will seal it in their future professional performance. Greater interdisciplinary communication between engineering and humanities professors is detonated since the teaching and follow-up of this Tec Week is conducted with the collaboration of both areas.

¡Sembremos!

Sembremos y dejemos a

la atmósfera moral que haga el resto,

como el labrador confía a la lluvia,

al aire y al sol sus semillas.

Aremos el suelo de la sociedad,

removiéndolo; agitémosla y sembremos

luego en ella ideas, abnegadamente,

sin pensar en nosotros mismos.

Lo demás vendrá con el tiempo.

Miguel de Unamuno

España, 1927

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Teaching and learning with Artificial Intelligence

Andreia Magalhães¹, António Andrade²

¹ Centro de Investigação para Desenvolvimento Humano, Universidade Católica Portuguesa, Portugal

² Centro de Estudos em Gestão e Economia, Universidade Católica Portuguesa, Portugal

Email: ammagalhaes@ucp.pt ; aandrade@ucp.pt

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Abstract

Artificial Intelligence (AI) has significant potential to revolutionize teaching and learning methods by providing innovative tools that personalize teaching and make the learning process more efficient. In this way, it is possible to create dynamic scenarios more easily, promoting the evolution of teaching towards a model based on the development of skills, which requires students to perform more actively. Considering that, between 2023 and 2024, Gartner places Generative AI at the peak of inflated expectations in its Hype Cycle, it becomes pertinent to analyze how learning and teaching with AI during this period. In this context, this work aims to conduct a scoping review using the Scopus database, covering the aforementioned period. The data obtained will be subjected to a content analysis, with the purpose of investigating the added value of AI in the way learning and teaching are carried out.

Keywords: Artificial Intelligence; Learning; Teaching.

1 Introduction

Artificial Intelligence (AI) is seen as an “omnipurpose technology” (Lee, 2023) that is transforming several sectors of society, including education. This is possible because, as we can see in Figure 1, AI integrates a growing set of modeling capabilities (U.S. Department of Education, 2023), whose major subfields of AI in construction are: (a) machine learning; (b) knowledge-based systems; (c) computer vision; (d) robotics; (e) natural language processing; (f) automated planning and scheduling, and (g) optimization (O’Brien, 2017).

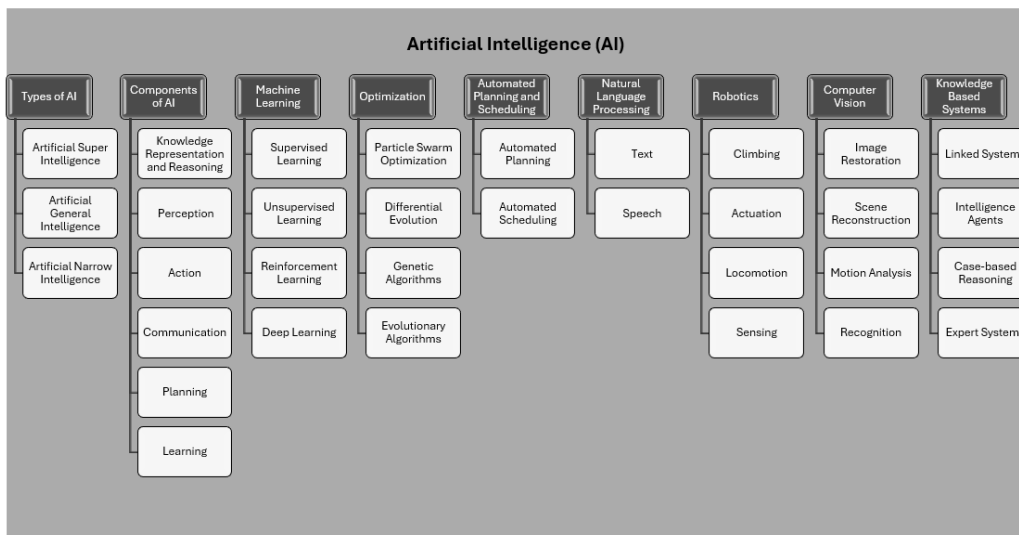


Figure 1 - Subfields and their components of AI based on Cardona et al (2023)

Thus, AI begins a revolution, unlike any other, because it is a tool with the capacity to create, sometimes without understanding how it reaches certain conclusions (some call it post-science), still with imperfections, in this initial phase, which can have negative impacts on teaching, as in all activities if, among other factors, there is a

cognitive transfer and not cooperation or critical reinforcement of our knowledge. However, the focus of this work is exclusively on knowing how to teach and how to learn with AI.

Thus, the potential of AI is systemic in education, for all levels of education, and encompasses scientific research, administrative and operational efficiency, AI teaching, teaching for a world with AI and teaching with AI, this being the central object of this study, since it is expected that, when integrated "into the educational system, it will significantly transform the learning environment and methodologies" (Summers, 2024).

Traditional teacher- and content-centered education faces profound challenges because, on the one hand, we have been facing the free globalization of knowledge sources for some years now and, on the other, in the face of AI resources that change the role of the teacher and allow for more personalized, active and promising teaching in promoting problem-solving skills. All this in a scenario in which it is estimated that 65% of students entering school will have professions that do not yet exist today (World Economic Forum, 2025).

In this sense, as Summers (2024, p.149) states, this is an "immersive opportunity to improve educational outcomes and access", as its integration into education creates an opportunity for the use of innovative tools that allow greater ease in creating dynamic scenarios that promote the personalization of teaching and the transition to a more efficient educational model based on the development of skills, which requires students to play a more active role.

Its integration into education is of real importance, as the United States of America, in several recent documents, highlights the important role of AI in national development, emphasizing education as a central area for its application (Carter, Kinnucan, Elliot, Crumpler and Lloyd, 2018; National Science and Technology Council, 2019; Office of Science and Technology Policy, 2016). Furthermore, the United States of America also introduced funding mechanisms to help students, from primary to higher education, increase their knowledge of AI (Congress, 2020). Similarly, in the United Kingdom, the Office for Artificial Intelligence (2021) established a national AI strategy to design the integration of AI into a variety of educational scenarios. Given that the adoption of AI in teaching may still involve a large dispersion of tools or rely on its progressive integration into LMSs that already have advanced skills such as: structuring a subject, creating question banks, carrying out tests, assessment grids, but also including chatbots for Socratic dialogue and role play, providing feedback on work and open assessment questions, or managing groups of students involved in pedagogical case study processes.

Generative artificial intelligence (GenAI) refers to technology that uses machine learning techniques to generate new content, including text, images, and audio (Lim, 2023). The GenAI tools, launched in late 2022, have inspired rapid adoption among users worldwide (Lim et al., 2023), including teachers (Chiu, 2023). As GenAI continues to impact science jobs, it is essential to understand how AI can support the work of teachers and students. After all, with "rapid technological progress, the role of the teacher is not limited to imparting knowledge, but also to equipping students with the necessary skills" (Summers, 2024, p. 150).

Hope is reborn for better learning outcomes by solving Benjamin Bloom's 1984 The 2 σ Learning Gap through AI-based active tutoring, in which the "student begins to experience new experiences and new challenges, which are capable of developing other skills, such as creativity and autonomy, far beyond those foreseen in content-based teaching" (Camargo in Debal, 2020, p.77). To help with active tutoring, there is a set of active learning methodologies available that can be seen as a continuum, varying according to the degree of student autonomy and the complexity involved in their application (Lima et al., 2024). Figure 2 presents the continuum

of methodologies developed by Lima et al. (2024) inspired by a lecture by Professor Michael Prince in 2011, at the American Society for Engineering Education conference.

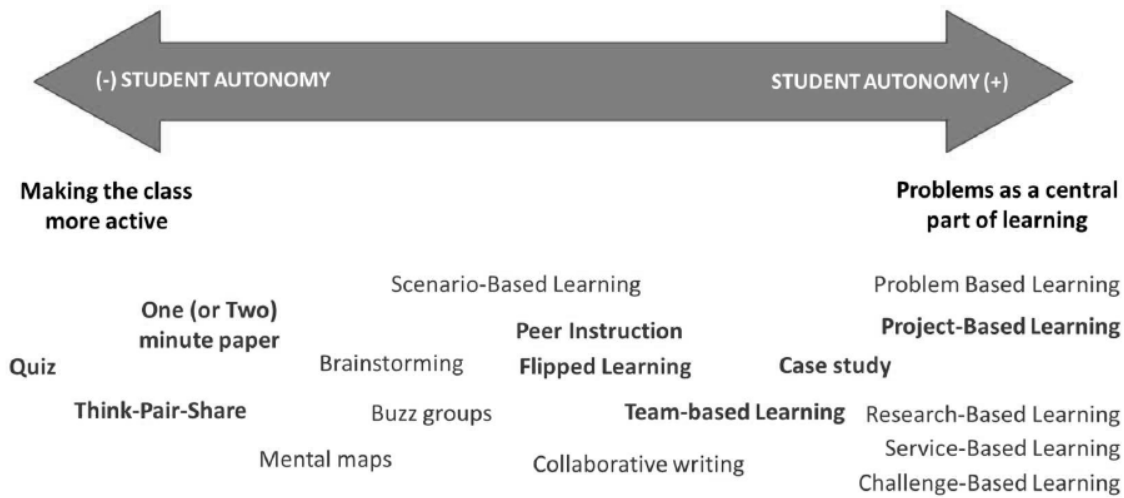


Figure 2 - Active Learning Continuum (Lima et al (2024) inspired by Prince (2011))

To take advantage of the use of Artificial Intelligence tools in the classroom, it is necessary that pedagogy, content and technology "coexist and influence each other" (Sampaio, 2013), a model called Technological Pedagogical Content Knowledge (TPACK), presented in figure 3.

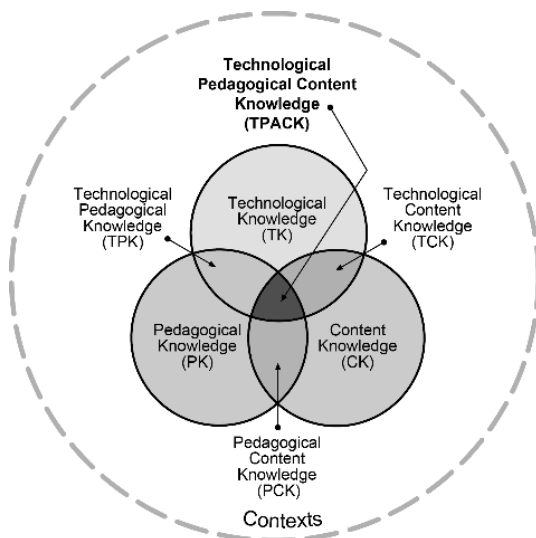


Figure 3 - Technological Pedagogical Content Knowledge (TPACK)

This model, according to (Cox, 2008), consists of "the appropriate use of technology, in a given curricular area, integrated into a specific pedagogical strategy, in a given educational context, to develop students' knowledge on a given topic or achieve a previously identified educational objective". In this way, the development of problem-solving skills in real and contextualized situations is encouraged, emphasizing active participation and shared responsibility for learning through group activities, debates and immediate feedback and reproducing and testing knowledge and skills through the creation of new scenarios or real life.

Like this, between 2023 and 2024, Gartner positions Generative AI at the peak of the inflated expectations of its Hype Cycle, resulting from the fact that “organizations across all industries have planned and implemented generative AI solutions at an unprecedented pace among emerging technologies” (Cribbs, 2024). Figure 4 illustrates the evolution of emerging technology trends and their impact on business strategies over time.

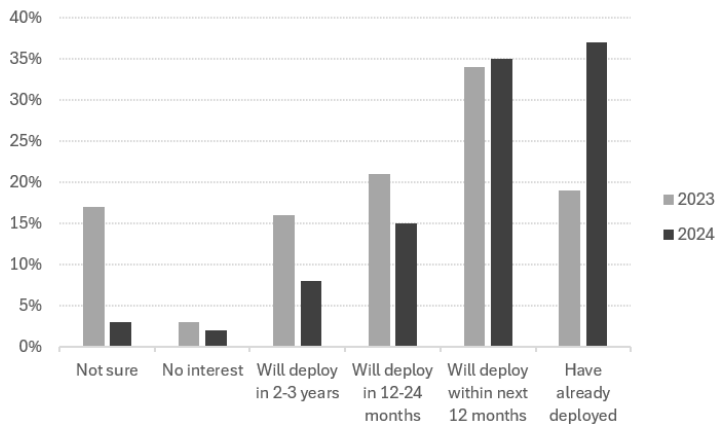


Figure 4 - Generative AI Solutions Are Deploying at an Unprecedented Pace based on Gartner by Cribbs (2024)

According to Gartner in Cribbs (2024), based on the content of the cases included in his survey, he presents a detailed analysis of emerging trends in technological education, highlighting “AI - content creation”, “AI - content discovery”, “AI - simulations” and “conversational AI”. These are the result of the significant increase in the adoption of digital tools and online learning platforms, driven by the need for innovation and adaptation to new teaching methodologies, promoting more interactive and personalized learning.

Given this scenario, it is essential to analyze how AI is being integrated into teaching and learning processes during this period. In this sense, we intend to present a scoping review, using the Scopus database, to verify, through the works presented during this period, how AI is learned and taught, that is, how it is being integrated into teaching and learning processes, identifying the main trends and challenges associated with the implementation of AI in educational institutions, as well as the best practices to maximize the benefits of this technology.

2 Methodology

The research methodology describes the structure of a study by explaining the procedures, methods and techniques necessary for developing the research, with the aim of obtaining reliable knowledge and determining the veracity of the facts (Gil, 1989). In this sense, considering the type of data to be collected, it was identified that the most appropriate methodology for this study is qualitative, as these methods “emphasize the specificities of a phenomenon in terms of its origins and reason for being” (Haguet, 2005, p.63) and are “oriented towards the construction of comprehensive models of what is being studied” (González R., 2005).

Thus, this qualitative research was based on documentary analysis which, according to Quivy and Campenhout (2008), is especially appropriate when one intends to study social changes and historical development, as is the case of this work. The authors also add that this methodology has the benefit of taking advantage of the wealth of available documents, specifically in electronic databases.

This scoping review is structured based on the proposal by Kitchenham et al. (2009) and aims to analyze the use of AI to find out: how we learn with AI and how we teach with AI.

In this sense, this research began with the collection of scientific articles obtained from Scopus databases, between 2023 and 2024, the peak period of this technology, and using the search keywords "AI", "teaching", "learning", and "leadership".

As a result of the search, 47 articles appeared, but after applying the inclusion criteria and analysing the abstract, a sample of 21 articles were selected. The remaining articles were excluded because they did not meet the selection criteria.

3 Results

For each article in the sample collected, a content analysis was carried out, based on categories that answer the questions raised. Thus, Table 1 presents the categories and examples found through content analysis to answer the question: How do we learn with Artificial Intelligence?

Table 1 - Learning with Artificial Intelligence

Category	Examples
Assisted Environments	Useful tool for environments where learning resources are scarce. Valuable tool for filling gaps in learning opportunities. Facilitates the creation of digital content and promotes collaborative learning environments. Provides personalized assistance and explanations. Valuable resource for clarification on complex topics or assistance with assignments. Provides opportunities to enhance learning experiences through tutoring, immediate feedback, and access to extensive educational resources.
Productivity and Academic Performance	Plays a key role in transforming student productivity and increasing academic performance. Contributes to a significant improvement in student productivity and academic performance, laying the foundations for more effective and adaptable learning.
Efficiency and Collaboration	It can increase student efficiency by providing resources, improving language skills, and promoting collaboration. Increased collaboration among students, creating a more engaging learning environment. Support tool that can save time and effort.
Skills Development	Improves language skills. Increases learning efficiency. Increases motivation. Supports students' psychological needs for autonomy, competence and relationships, promising to improve self-determination, motivation and academic performance. Provides a personalized approach, improves understanding and engagement, and promotes a more conducive learning environment.
Content Creation	It helps students generate content based on their unique perspectives, assisting them with tasks such as editing or translation. It helps students design products and optimize business practices, offering potential benefits for economic development.
Interactive Support and Virtual Tutoring	They can provide multimedia learning resources, promoting active/self-regulated learning among students. They can provide personalized content and learning paths taking into account students' interest, aptitude and behavioral profile. They can support students' personalized learning, extending learning opportunities beyond classroom time and consolidating learning outcomes. Students can receive continuous interactive learning support at all times outside of regular class hours. It can act as a virtual tutor, answering students' questions and providing personalized learning experiences.

It can provide personalized math tutoring to students, with improved learning outcomes through explanations tailored to students' misconceptions.
 It answers questions, summarizes information, facilitates collaboration, checks concepts, prepares for exams and provides feedback.
 It helps solve complex problems, develop reading and writing skills, create practice exercises and quizzes, and develop analytical and innovative thinking.
 It improves group dynamics by suggesting a discussion structure and providing real-time feedback.
 Identifies gaps in students' prior knowledge, indicating tools and learning materials to support student growth.

Table 2 presents the categories and examples found through content analysis of the sample of articles to answer the question: How do we teach with Artificial Intelligence?

Table 2 - Teaching with Artificial Intelligence

Category	Example
Collaborative and Personalized Learning	It helps in collaborative learning between teacher and student, intelligent tutoring systems, automated assessment and personalized learning. It can enhance active, collaborative and personalized learning experiences. It helps in generating materials and guiding students. It can meet individual support needs and contribute to personalized learning.
Integration in Education	Creating quiz questions and feedback on student writing. With the potential to reshape traditional tasks and assessments in education.
Automation and Efficiency	It empowers teachers to make data-driven decisions as they review and improve teaching and learning practices, which helps them predict student outcomes. It helps teachers understand the student learning process by identifying critical factors that can impact student learning outcomes. It helps them make informed decisions, provide responsive pedagogy, offer differentiated learning, and provide timely feedback.
Transformation and Innovation in Education	It marks a fundamental transformation in the way knowledge is acquired, disseminated and applied. Teachers analyze student learning data to gain a better understanding of their learning situation, enabling more personalized teaching guidance and scenario design.
Personalized Instructions and Adapted Testing	It fosters a supportive learning environment, helps implement innovative teaching practices, and ensures equity in education. It provides teachers with tools to increase efficiency and effectiveness in individualized learning. It alleviates teachers' administrative workload and supports personalized learning. It provides extra time that can be used for targeted feedback, personalized learning plans, and professional development activities. AI-powered grading also eliminates bias, ensuring fair and objective assessments of student work. It can free up teacher time by helping with repetitive and bureaucratic tasks. It frees up time for more human tasks, such as building relationships with students and collaborating with colleagues. It helps design resources and create tools that uniquely meet the needs of each student, and it is the basis for algorithmic scoring systems that provide feedback on students' writing, assignments, and exams and allow teachers to focus on more creative or relational efforts. It helps predict student performance and prompt organizational interventions to help prevent non-completion or course failure.

4 Discussion

The results obtained show that Artificial Intelligence (AI) in education is transforming both teaching and learning, providing new opportunities and approaches for students and teachers.

Thus, AI can fill gaps, provide essential educational support and facilitate the creation of digital content (Aanders, 2023). Furthermore, it promotes collaborative learning environments and adapts to individual

students' needs, offering personalized assistance and explanations (Shabbir, 2024). It also plays a key role in transforming student productivity and increasing academic performance, laying the foundation for more effective and adaptive learning (Shabbir, 2024).

In this way, AI can increase student efficiency by providing resources, improving language skills and promoting collaboration (Kasneci, 2023) and assist students by offering multimedia learning resources that promote active and self-regulated learning (Rahayu, 2022). Ultimately, it can act as a virtual tutor, answering students' questions and providing personalized learning experiences (Han, 2023).

In education, AI promotes a supportive learning environment, helping to implement innovative teaching practices and ensure equity in education (Luo, 2024) that facilitates collaborative learning between teacher and student, through intelligent tutoring systems, automated assessment and personalized learning (Shabbir et al., 2024). It has the potential to reshape traditional tasks and assessments in education, providing a more efficient approach tailored to the needs of students (Rice, 2023). Because it is data-driven, it helps teachers predict student outcomes and improve teaching and learning practices (Cheng & Wang, 2023), in order to prevent non-completion or failure of the course (Akgun & Greenhow, 2022).

Therefore, AI is redefining the educational landscape, providing teachers with tools to increase efficiency and effectiveness in individualized learning, alleviating the workload in administrative areas and supporting personalized learning (Fullan, 2023).

5 Conclusion

Artificial intelligence (AI) has the potential to transform teaching and learning methods by offering new opportunities to personalize and optimize the educational process.

Thus, it turns out that AI can be used to teach, because it allows teachers to personalize instruction according to the individual needs of students. AI tools can analyze student performance and provide immediate feedback, helping teachers identify areas that need more attention. In addition, AI can automate administrative tasks, allowing teachers to focus more on pedagogical development and direct interaction with students.

AI enables learning because students benefit from more adaptive and interactive learning. AI-based learning platforms can adjust content and pace based on individual students' progress and preferences. AI also facilitates access to diverse educational resources and immersive learning experiences, such as simulations and augmented reality, which make the learning process more engaging and effective.

In short, we can harness the power of AI to create enriching and inclusive learning experiences that prepare students for the challenges of the future. Its harmonious integration into the education system has the power to transform education, making it more accessible, personalized and effective.

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Immersive Classroom with Augmented Reality: Cognitive Evaluation and Perceptions of Production Engineering Students in Assembly Assistance

Eugenia Cornils Monteiro da Silva¹, Antônio Augusto Maciel Guimarães², Marcelo Carneiro Gonçalves³, Marcelo Becker⁴, Sanderson Cesar Macedo Barbalho⁵

¹ University of Brasília, Production Engineering and Mechatronic Engineering Departments, Brasília, Brazil.

² University of Brasília, Production Engineering Departments, Brasília, Brazil

³ University of Brasília, Production Engineering and Mechatronic Engineering Departments, Brasília, Brazil

⁴ University of São Paulo, São Carlos School of Engineering, Department of Mechanical Engineering, Mobile Robotics Group – Robotics Lab (LabRoM), São Carlos, Brazil.

⁵ University of Brasília, Production Engineering and Mechatronic Engineering Departments, Brasília, Brazil.

Email: eugeniacornils@gmail.com, 190084421@aluno.unb.br, marcelo.goncalves@unb.br, becker@sc.usp.br, sandersoncesar@unb.br

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Abstract

This paper presents an interactive experience with an experimental augmented reality prototype for assisting in the assembly of parts in an academic environment. The research was carried out with students studying Information Systems in Production Engineering, who took part in practical tests using assembly assistance system based on augmented reality (AAS). During the activity, the students assembled a locomotive following the guidelines designed by the system, which used Deep Learning to recognize parts and detect hand movements. The experiment used three RGB cameras to capture the assembly process, allowing automatic analysis of the students' interactions with the system. Over the course of three lessons, the students were instructed to follow the assembly suggestions provided by the AAS. At the end, a questionnaire was applied to assess the cognitive load of the activity and understand the students' perception of the interaction with the experimental bench. The results indicated that the use of augmented reality helped them to understand the assembly steps and the association between process modeling notation and emerging technologies such as Deep Learning. In addition, the students provided feedback on challenges faced, such as improving the interface and increasing accuracy in detecting movements. This experience demonstrated the potential of immersive technologies in teaching and industry, highlighting how assembly assistance systems can not only enhance academic training, but also optimize industrial processes in the future.

Keywords: Assembly Assistance System; Skills.

1 Introduction

Technological advancements in recent years have significantly reshaped industrial processes through the integration of emerging technologies under the framework of Industry 4.0. Concepts such as artificial intelligence, the Internet of Things, augmented reality, and cyber-physical systems have revolutionized the way products are conceived, manufactured, and monitored across multiple industrial sectors (Schwab, 2016). This transformation demands a workforce equipped with advanced technological competencies and socio-technical skills that align with the complexities of modern production systems (Trevelyan, 2019).

However, higher education institutions, particularly those offering programs in engineering and technology, often struggle to match the rapid pace of industrial innovation (Trevelyan, 2019). Curricular frameworks and pedagogical practices remain, in many cases, anchored in traditional approaches that do not fully reflect the realities of contemporary engineering environments. Consequently, there is a pressing need to revise and modernize academic syllabi to incorporate practical experiences and technological tools that mirror those used in advanced industrial settings (Garcia Castro et al., 2024).

Among these tools, collaborative human-machine interaction systems represent a critical component of the current industrial paradigm. These systems, which facilitate seamless integration between human cognition and machine intelligence, are increasingly central to the operation of smart manufacturing environments (Trevelyan, 2019). Their inclusion in engineering education can serve as a bridge between theoretical knowledge and industrial application, fostering experiential learning and enhancing students' readiness for the workforce (Garcia Castro et al., 2024).

In response to this educational gap, a national prototype was developed through a collaborative project. The prototype features a reality-augmented assembly assistance system that integrates three RGB cameras, a LG projector, and a computational unit capable of real-time object and hand tracking.

The prototype projects visual guidance directly onto the workspace, supporting the user through successive stages of a predefined assembly process. A synthetic dataset, generated through data augmentation techniques, underpins the object recognition system, ensuring robust performance across variable conditions. This integration of hardware and software creates an immersive, feedback-oriented learning environment that emulates real-world manufacturing contexts (Romero et al., 2021).

The present study aims to evaluate students' perceptions of their interactions with the system during assembly activities conducted in an academic setting. By analyzing their feedback, the study seeks to assess the pedagogical potential of such assistive technologies and explore how they can be effectively incorporated into engineering curricula to better prepare students for the demands of Industry 4.0.

Therefore, this study is framed as an exploratory case study aiming to investigate the perceptions of Production Engineering students when interacting with a prototype under development of an augmented intelligence system for assembly assistance. The research seeks to understand how students evaluate the usability, cognitive load, and pedagogical potential of the technology in an educational setting, contributing to system refinement and to future applications in engineering learning environments.

2 Materials and Methods

This study is characterized as exploratory in nature, with the aim of analyzing student interaction with a national prototype of an assembly assistance system, developed at University in Brasília. The focus of the investigation was to understand students' perceptions and identify possible methodological improvements in the use of the prototype in practical learning contexts with Industry 4.0 technologies.

The purpose of the activity was to simulate for the students the dynamics of a real experiment, as typically conducted in the development of scientific research. In this way, the activity aimed to provide a practical and reflective experience, bringing students closer to the methodological steps involved in data collection and analysis, while fostering critical thinking and understanding of scientific investigation procedures.

The research was conducted with students regularly enrolled in the SIEP (Information Systems) course. The experiment took place in a laboratory environment, using an interactive augmented reality workbench capable of recognizing parts and identifying hand movements in real time.

The first methodological stage involved the presentation and signing of the Informed Consent Form (ICF), ensuring that the participants were aware of the objectives of the research, the use of the information and their freedom to participate. The students were then given an introductory explanation of how the bench worked, the objectives of the assembly and how to project the instructions. They then began to assemble a playful object - a little train - with parts recognized by the system from a database enriched with data augmentation

techniques. During the activity, the students followed instructions projected onto the workbench, which guided the order and correct positioning of the components.

After completing the assembly, the participants answered a structured questionnaire based on the instrument, which aims to measure the perceived workload in activities involving interaction with technological systems, considering dimensions such as mental effort, physical effort, time, perceived performance, frustration and overall task demand.

The data collected through the questionnaires was analyzed qualitatively and quantitatively, seeking to identify patterns of perception, strengths and limitations in the students' experience with the prototype. The results obtained contributed to reflection on teaching methodologies that incorporate emerging technologies, as well as improving the system as a teaching support tool in university environments.

2.1 Methodology for Analyzing the Student Experience

To assess the students' perception of the practical class experimenting with the augmented reality prototype, a digital form was used as a data collection tool. The main objective was to analyze the participants' experience of using the proposed technology.

In the first section of the form, the terms of welcome to the research were presented, including thanks for participating, the estimated time to complete the form, detailed instructions on how to answer the questions and information on the confidentiality of the data collected.

The second section aimed to collect the profile of the respondents. Information was collected on gender, age group, current occupation or previous professional experience, schooling, previous experience in assembly activities, familiarity with technologies in general, ability to concentrate, previous experience with augmented reality and the level of comfort in following written and visual instructions.

This study is characterized as exploratory in nature, with the aim of analyzing student interaction with a national prototype of an assembly assistance system, developed at University in Brasília.

In addition, the form included an assessment of the mental demand involved in carrying out the practical activity. Although the full index was not applied, the dimension related to cognitive effort was considered, including aspects such as perceived physical effort, concentration, reasoning, attention and thought load. The inclusion of this item was aimed at identifying the level of mental demand of the proposed task and providing input for future improvements to the prototype, as well as understanding the students' experience during interaction with augmented reality technology.

3 Innovations in Engineering Education

This section presents educational experiences that have used emerging technologies as a teaching tool, highlighting practices that involved direct experimentation by the students. Studies are discussed which demonstrate the results obtained through the application of active methodologies using resources such as augmented reality and interactive simulations.

Some authors point out that traditional teaching techniques no longer meet the demands of contemporary industry and that new teaching approaches are needed to promote greater alignment between academic training and the demands of the professional market (Leung et al., 2008; Romero et al., 2021; C. Zhang et al., 2025; X. Zhang et al., 2021). As demonstrated by Latifah et al. (2020), this expository format, still widely used in technical subjects, restricts opportunities for developing essential skills such as critical thinking, autonomy, collaboration, and the practical application of knowledge. These limitations reinforce the inadequacy of this

model in meeting the current demands of the industry and the challenges of engineering education, highlighting the need for more active and contextualized methodologies that promote student agency and integrate theory with practice.

In this context, the article analyzed proposes the integration of Design-Based Learning (DBL) and Outcome-Based Education (OBE) as an innovative methodology for teaching Industrial Engineering. This approach favors the development of systemic and critical thinking, problem-solving skills, teamwork, autonomy in learning and innovation among students. To investigate the effects of this methodological proposal, two practical experiments were carried out: the first involved a project applied to optimizing the storage and protection of metal parts in a company, focusing on the 5S tool; the second consisted of a comparative study between an experimental class, which used the DBL+OBE methodology, and a control class, subjected to traditional teaching. The didactic proposal emphasized student autonomy and active learning, as well as the practical application of theoretical content. Subsequent analysis of the experiences revealed that the students perceived the methodology as an opportunity to effectively integrate theory and practice, promoting greater engagement, collaborative work and direct contact with real industry problems, which contributed significantly to their professional training.

In the study carried out by Latifah et al. (2020), the Project-Based Learning (PBL) methodology was applied in technical engineering education, with the aim of comparing its effects in relation to the traditional expository model. The research involved two classes: an experimental class, which used PBL, and a control class, which was subjected to conventional teacher-centered teaching. The project was based on a real problem related to poor sanitation in the city of Garut, Indonesia, challenging students to develop solutions for the implementation of community septic tanks in densely populated areas. The use of educational technologies, such as simulation tools and computer-aided design, was integrated into the teaching process, helping to make the experience more contextualized and applied. The results indicated significant gains in the development of students' practical and interpersonal skills, while at the same time valuing the role of students in leading their own learning.

Another relevant case of success in the use of experimental practices in engineering education is presented by Zhang et al. (2025), who proposed an innovative practical lesson for teaching the wave-particle duality of light in Optics courses. The study showed that by using modern instruments such as optical fibers, three-dimensional optical traps and interferometry systems, students were able to simultaneously visualize the wave and corpuscular behavior of light - something that is difficult to understand in purely lecture-based classes. In addition, the students had the opportunity to develop practical skills relevant to the context of contemporary engineering, such as handling advanced optical equipment, interpreting experimental data and solving technical problems autonomously. These results highlight the importance of integrating educational technologies and active learning methodologies to train engineers who are better prepared for the challenges of today's market.

It is now increasingly common to develop applications and assistance systems based on deep learning algorithms to prevent errors in manual assembly processes in industrial environments (Gellert et al., 2020; Riedel et al., 2021). These systems play a key role not only in reducing operational failures, but also in improving operator training, both in manufacturing contexts and in academic environments.

4 Results of the Practical Educational Activity with Augmented Reality

The next two subsections present the results: Subsection 4.1 outlines the students' profiles and contextualizes their participation in the experiment, while Subsection 4.2 offers an individualized analysis of cognitive load levels and perceptions to assess the experiment's impact on learning.

4.1 Characterization of the Respondents and Structure of the Experimental Study

All respondents were higher education students. Among the eight participants, only one identified as female. The predominant age group was 18 to 24 years ($n = 7$), with only one participant falling into the 25 to 34 range. Regarding familiarity with technology, five participants (62%) reported frequent use without advanced proficiency, while three (38%) indicated daily use of advanced technologies, suggesting high familiarity.

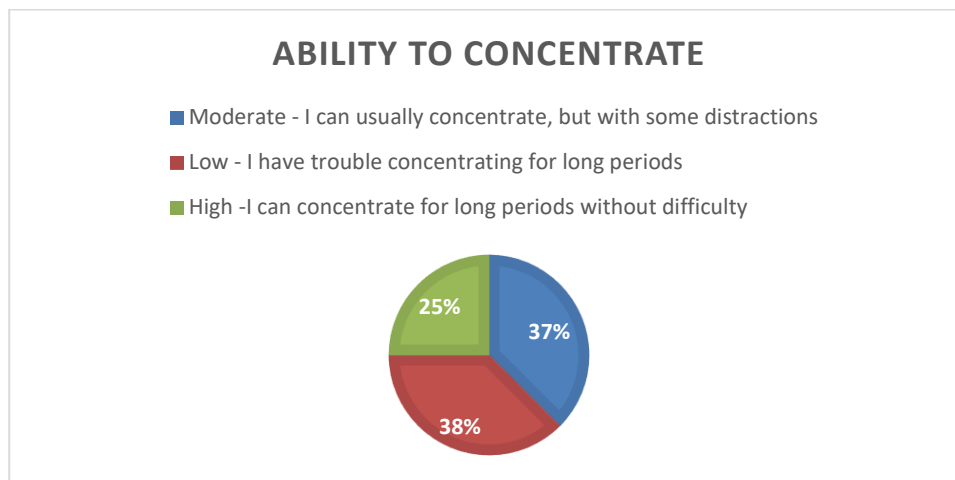


Figure 1. Participants' ability to concentrate

In terms of concentration capacity during task execution, three participants reported a moderate level, with occasional distractions; another three indicated low capacity for prolonged focus; and two described high ability to maintain concentration over extended periods (Figure 1).

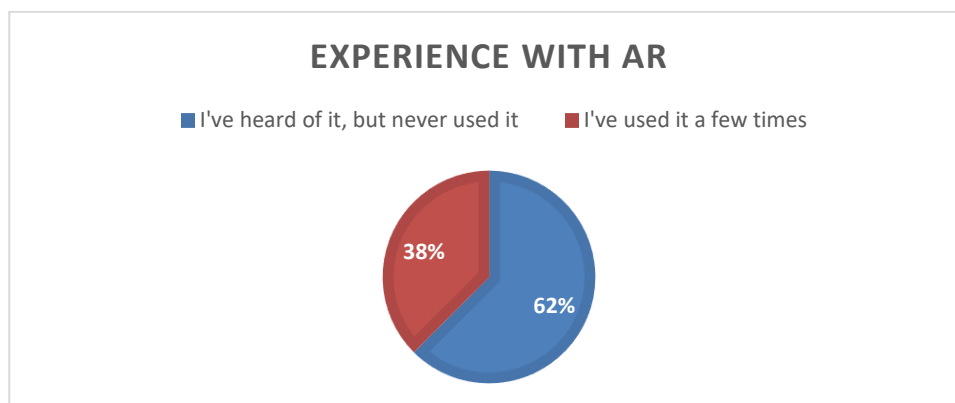


Figure 2. Participants' experience with AR (augmented reality)

With respect to prior experience with augmented reality (AR) technologies, five participants stated they were only theoretically familiar, never having used the technology, while three reported having used it at least once (Figure 2).

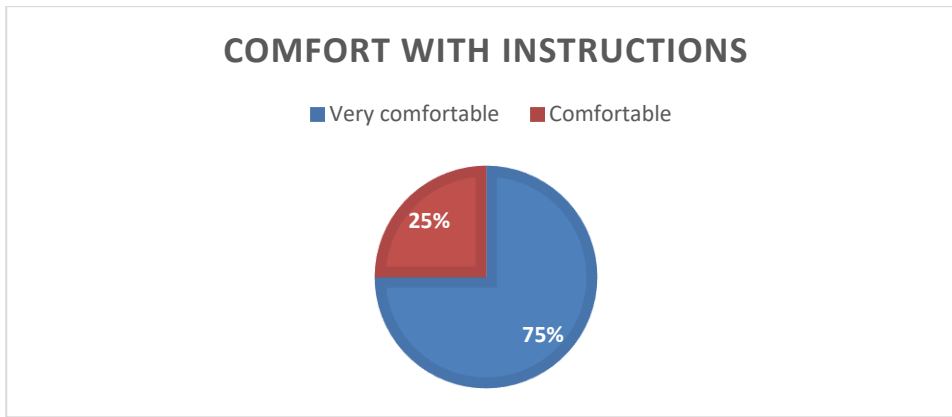


Figure 3. Participants' comfort with instructions

And in relation to comfort in following written or visual instructions, six participants indicated feeling very comfortable, whereas two reported being moderately comfortable (Figure 3).

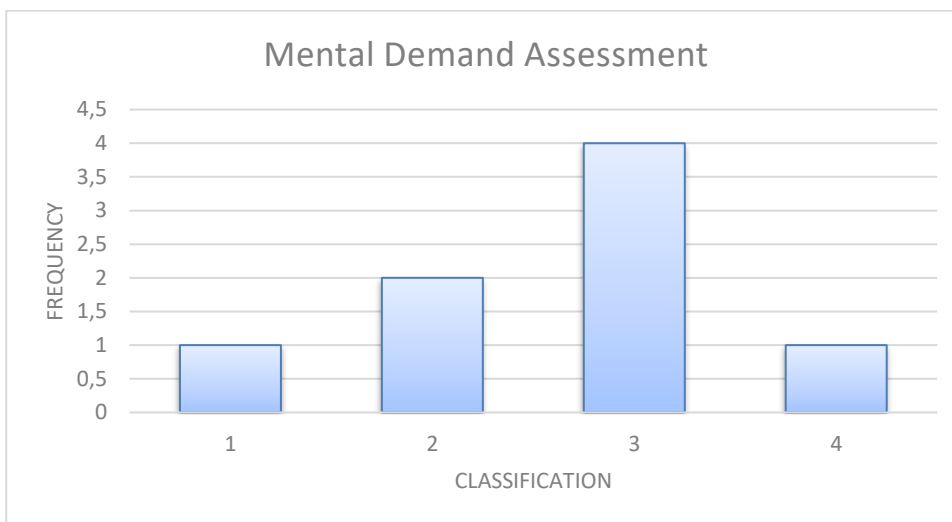


Figure 4. Mental Demand Assessment

Figure 4 shows the levels of mental demand perceived by the students during the activity with the augmented reality prototype. The classification was made on a scale of 1 to 5, with 1 indicating low demand and 5 extremely high demand. The most common rating observed was 3, given by four participants. This score suggests a moderately high perceived mental load, indicating that the students felt a significant but still manageable cognitive effort. Next, rating 2 was given by two participants, representing a lighter cognitive demand. Ratings 1 and 4 were chosen by one participant each. A total of eight students took part in the experiment, which confirms the total responses shown in the graph.

5 Conclusions

Based on the literature and the findings of this study, it can be concluded that the use of augmented reality significantly supported students in understanding the steps involved in assembly processes and in establishing connections between process modeling notation (BPMN) and emerging technologies such as Deep Learning. The feedback provided by students also revealed important challenges, particularly regarding interface improvements and the need for greater accuracy in movement detection. Overall, the experience confirmed

the educational and industrial potential of immersive technologies, demonstrating that assembly assistance systems not only enrich academic learning but also hold promise for enhancing efficiency and precision in industrial operations.

Furthermore, this study highlights the importance of offering engineering students not only theoretical exposure but also practical engagement with emerging technologies such as augmented reality—especially when these systems are still in development. Such experiences can empower students to apply these technologies in real-world industrial contexts and even inspire them to develop or adapt similar solutions in their future professional environments. Therefore, integrating interactive and experimental components into engineering curricula may contribute to fostering a new generation of professionals better prepared for the technological demands of Industry 4.0.

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Scalable AI-Driven Video Generation for Waste Picker Education: A Localized Approach Using Open-Source Models

Antônio Augusto Maciel Guimarães¹, João Mello da Silva¹, Márcia Longen Zindel¹, Eugenia Cornils Monteiro da Silva¹

¹ University of Brasilia, UNB

Email: antonio.guimaraes837@gmail.com; joao.mellos@gmail.com; marcialz@unb.br; eugeniacornils@gmail.com.

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Abstract

This paper presents the development of an AI-driven application designed to scale the production of educational videos for waste pickers within the Educado project, part of the Egalitarian program. The application integrates three open-source AI models, Flux AI for persona generation, Coqui AI for speech synthesis, and SadTalker for realistic lip-sync, allowing for the creation of engaging, locally produced educational content without reliance on external connections. Designed to run on relatively modest hardware (16-core CPU, 32GB RAM at 7400Mt/s, and 6GB dedicated VRAM), this solution ensures accessibility in resource-constrained environments. The goal is to address the challenge of efficiently generating high-quality educational materials that can be easily adapted to the specific needs of waste pickers, a crucial yet often overlooked workforce in waste management. The system enables the automatic creation of virtual educators, delivering spoken lessons with synchronized lip movements, simulating a real instructor. A key limitation is the management of multiple personas within a single video, which is currently mitigated by generating a character with a green screen background and layering them in post-production. The proposed framework demonstrates how open-source AI tools can enhance educational access for underserved communities while maintaining operational independence from cloud-based services. This paper details the implementation of the application, its challenges, and its potential for scalability in the production of educational content. Future work will focus on improving multi-persona integration, integrating another AI assistant that is tailored to specific areas of knowledge to aid researchers and also generating scripts using trusted references, and expanding the applicability of the system to broader educational contexts.

Keywords: AI-generated; Educational; Lip-sync; Open-source; Innovation.

1 Introduction

As part of the development of the EDUCADO project within the ERASMUS+ EGALITARIAN program, the primary goal is to produce educational content focused on financial literacy and occupational health and safety for solid waste pickers in Brazil. One of the main challenges encountered during implementation was the creation of videos that could effectively and efficiently convey knowledge to audiences with diverse educational backgrounds.

Traditional audiovisual content production requires a complex process, including studio rental, professional equipment, and detailed post-production editing. This approach is often costly, time-consuming, and limits scalability. To overcome these barriers, the project explored methodologies to automate and optimize video creation while preserving instructional quality and learner engagement.

This work adopts a design-based case study approach, integrating iterative field testing with solid waste picker cooperatives. This method allows for continual refinement of tools based on real-world feedback and needs, aligning well with engineering education principles of problem-solving, stakeholder engagement, and user-centered design (Barab & Squire, 2004).

In response to these challenges, the project adopted vlog-style videos—a format known for its informal, dynamic, and relatable presentation style. Vlogs facilitate more personal communication, improving audience connection and motivation, particularly in adult education contexts (Green et al., 2020). Research shows that

video content delivered through accessible, informal formats can significantly enhance learning outcomes and increase digital participation in marginalized communities (Yousef et al., 2014).

Beyond producing content for waste pickers, the project also supports the creation of digital personas representing workers and mobilizers—community members responsible for educating households on waste separation. These personas contribute to social legitimacy and extend the reach of awareness campaigns by providing culturally relevant and representative messaging. This approach leverages principles of participatory design and aligns with literature on the effectiveness of contextualized educational media (Clark & Mayer, 2023; Kali et al., 2018).

By combining innovative media formats with open-source AI tools, the EDUCADO project fosters a scalable and inclusive digital learning ecosystem. Educational videos can be distributed through social media and local networks, creating a decentralized, low-cost model of community-centered knowledge dissemination. This design-based innovation serves not only pedagogical objectives but also broader goals of digital equity and social inclusion.

2 Methodology

This study follows a design-based research (DBR) approach (Barab & Squire, 2004; McKenney & Reeves, 2012), which combines iterative development with real-world testing to refine educational tools through continuous feedback. The methodology integrates principles from engineering design, educational psychology, and open-source software development to build a system that is both scalable and socially impactful.

The software was developed in stages, beginning with the identification of user requirements and progressing through iterative cycles of design, testing, and optimization with cooperative waste picker communities in Brazil. The process emphasized contextual adaptation, learner inclusiveness, and low-barrier deployment.

To ensure alignment with pedagogical, technical, and accessibility goals, a set of development principles was established.

2.1 Design Guidelines and Pedagogical Parameters

To ensure that the software aligned with both its pedagogical goals and technical feasibility in low-resource environments, a set of engineering design parameters was established. These guidelines reflect the principles of user-centered design and iterative refinement common in engineering and software development (Sommerville, 2015; McKenney & Reeves, 2012), and they were shaped by ongoing collaboration with the target audience through the EDUCADO fieldwork.

- **Ease of Use:**
 - The software was designed to be intuitive for users with limited digital literacy. Interface decisions were informed by usability engineering principles (Nielsen, 1994) and validated through user testing in waste picker cooperatives. Clear visual steps and modular automation allow users to create video content without prior technical training.
- **Fidelity in Representation:**
 - Visual and instructional consistency was prioritized to enhance trust and recognition. A standardized set of colors, fonts, and avatars was used to reinforce brand identity and maintain clarity across multiple educational topics. This aligns with research showing that consistent design improves learner focus and message credibility (Clark & Mayer, 2023; Holden & Butler, 2003).
- **Accessibility through Open-Source Tools:**
 - The system uses only free and open-source models, ensuring legal freedom for adaptation and reducing barriers to use in community-led initiatives. This aligns with long-standing open

software values around educational freedom (Stallman, 2002) and supports knowledge democratization in engineering education.

- Low Operational Cost:
 - By enabling offline execution on mid-tier hardware, the platform eliminates dependence on cloud services, which are often unaffordable or unavailable in marginalized communities. The model operates with only a 16-core CPU, 32GB RAM, and a 6GB GPU—demonstrating how resource efficiency is a key enabler of digital inclusion (Abadi et al., 2016).
- Realism in Presentation:
 - The integration of AI-powered lip-sync (SadTalker) and expressive avatars improves the clarity and perceived authenticity of instructional content. Research on multimedia learning confirms that realistic visual and auditory synchrony enhances understanding and engagement (Mayer, 2005; Clark & Mayer, 2023).

These development principles not only guided the technical architecture of the EDUCADO application but also serve as a pedagogical framework for engineering students and educators interested in building equitable digital solutions. The design process offers a replicable model for socially relevant educational innovation, emphasizing simplicity, openness, and contextual fidelity.

2.2 Software Architecture and Module Breakdown

The software was structured around a modular architecture to enable flexible development, efficient resource use, and user-oriented interaction. This modularization also allowed iterative testing and refinement in real learning environments, consistent with the principles of design-based research (Barab & Squire, 2004).

Each module performs a specific function in the pipeline of video lesson generation, contributing to the system's overarching educational goals: accessibility, scalability, and pedagogical effectiveness.

2.2.1 Module 1 - Data Input and Content Configuration

The user begins by inputting the lesson script and selecting a character for the video. Options include choosing a pre-designed avatar or generating a new one using pre-set parameters. This module emphasizes ease of use and was designed with usability heuristics in mind (Nielsen, 1994). Field testing showed that users with minimal technical background could successfully complete this step, validating the system's design for low-barrier use in community settings.

2.2.2 Module 2 - Image Generation with AI

The image generation module uses Flux AI to produce character images aligned with predefined visual guidelines. The AI generates images using a 9:16 format optimized for mobile display, with parameters for lighting, background, and expression embedded in the prompt.

Users can iterate through outputs until a suitable image is selected, ensuring personalization and cultural relevance. These visual outputs contribute to learner engagement and identification, both essential for effective educational media (Clark & Mayer, 2023). The module balances visual quality with processing efficiency, running locally even on mid-range hardware (Abadi et al., 2016).

2.2.3 Module 3 - Text-to-Speech (TTS) and Voice Cloning

This module converts the lesson script into speech using the Coqui AI model. While initial attempts at custom training required significant resources, the final implementation uses pre-trained models with small-scale fine-tuning to retain realism and clarity. The voice output is synchronized with the selected persona and supports regional linguistic features for relevance.

According to principles of multimedia learning (Mayer, 2005), realistic, well-paced narration significantly improves knowledge retention. This module's success was validated through field sessions where waste pickers showed increased attention and comprehension when hearing familiar speech patterns.

2.2.4 Module 4 - Lip Synchronization and Animation

To animate the avatar with realistic facial expressions and lip movements, the system employs SadTalker. This model enables synchronized animation based on the generated speech and static image. Beyond syncing lip movement, it incorporates subtle expressions and eye/head movements that enhance the illusion of a human presenter.

Feedback from pilot deployments highlighted that learners perceived these avatars as more "relatable" and "trustworthy" than traditional animated or slide-based videos. This aligns with findings that personalized, expressive content improves learner engagement in informal education (Green et al., 2020; Clark & Mayer, 2023).

2.2.5 Integration and Workflow Efficiency

Each module operates in a virtual environment to isolate dependencies and prevent compatibility issues, following best practices in software engineering (Sommerville, 2015). The pipeline supports CLI (command-line interface) execution to optimize performance and reduce overhead, critical in environments with limited digital infrastructure.

The modular design also enables future extensibility, such as multi-avatar scenarios or integration with AI script assistants. Throughout development, field testing in waste picker cooperatives provided crucial feedback for improving usability and refining system outputs, an essential element of the design-based research cycle (McKenney & Reeves, 2012).

3 Implementation and Field Evaluation

The development of said application followed a structured and iterative approach to optimize execution time and resource utilization. To ensure efficiency and modularity, each component was developed independently while maintaining seamless integration in the final video generation workflow. The primary development steps were as follows:

- Virtual environment setup:
 - Each AI model used in the application required specific software dependencies and libraries, making it unfeasible to run them all in a single environment without conflicts. To address this, isolated virtual environments were created for each model, ensuring compatibility with specific Python versions and dependencies. This setup was managed using Conda and Python's native virtual environments, allowing independent execution of each module while avoiding package conflicts. Research on software engineering best practices highlights that isolating dependencies improves system stability and prevents compatibility issues in AI-driven applications (Abadi et al., 2016).
- Validation of required libraries:
 - The AI models used in the software relied on several libraries for proper functioning. Key dependencies such as PyTorch, TensorFlow, and Librosa required specific versions to ensure compatibility with the selected models. Each environment was configured to include only the strictly necessary libraries, reducing unnecessary memory consumption and processing overhead. This approach optimizes performance and minimizes the risk of unexpected failures during execution (Abadi et al., 2016).
- Validation of native execution:

- A core requirement of the project was ensuring that all models could run locally without relying on external servers or cloud-based APIs. This decision was essential to maintain data privacy, avoid recurring operational costs, and increase accessibility in low-connectivity environments. However, some models were initially developed for Linux environments, posing a challenge since the application needed to run on Windows. To overcome this, compatibility layers such as Windows Subsystem for Linux (WSL) and MinGW were tested, enabling the execution of Linux-based libraries within the Windows environment. Studies confirm that local execution of AI models significantly enhances security and reduces long-term maintenance costs (Stallman, 2002).

After validating these three foundational aspects, each software module was developed independently, leading to specialized processes for image generation, text-to-speech conversion, video synthesis, and final application execution.

3.1 Image generation

The first module developed was the image generation system, powered by Flux AI, an open-source model selected for its resource efficiency and ability to generate expressive avatars. The model was fine-tuned to prioritize waist-up, well-lit compositions in a 9:16 aspect ratio, optimizing output for mobile devices—the primary platform used by waste pickers and mobilizers.

A user feedback loop was implemented, allowing iteration on generated images. For example, keywords like “neutral background” or “smiling” produced more consistent results, reducing user frustration. This iterative improvement supported accessibility for non-technical users while enabling identity representation through culturally appropriate visual cues.

On average, each image required 6–10 minutes of processing using a 16-core CPU and 6GB GPU. The trade-off between rendering quality and processing speed was continuously evaluated, favoring usability in constrained environments.

3.2 Text-to-speech conversion

The second module performs text-to-speech (TTS) conversion using the Coqui AI voice cloning framework. After initial experiments with large custom voice datasets proved hardware-intensive, the team opted for a pre-trained model with fine-tuning based on 3 hours of targeted recordings.

This compromise allowed for natural-sounding, regionally appropriate voices to be deployed locally. A two-minute voice file could be generated in under 40 seconds. Based on multimedia learning principles (Mayer, 2005), the use of conversational tone and clearly paced narration improved message retention and user engagement.

Field feedback led to adjustments in voice pitch and emphasis to match local idioms and reduce cognitive load.

3.3 Video generation

The third module combines voice and avatar image using SadTalker, an AI model designed to synchronize lip movement and generate realistic facial expressions. This module not only aligns speech and visual output but also introduces subtle head and eye movements for added realism.

Processing time for a 1–2 minute video ranged between 8–14 minutes, depending on complexity. The choice of this model was based on its compatibility with still images and the quality of expressiveness—both key to maintaining attention in video-based learning.

This approach significantly outperformed traditional slide narration, especially in community feedback, where users described the experience as “watching a person explain,” instead of “just hearing a machine.”

3.4 Standalone executable application

To ensure usability in real-world settings—including cooperatives and educational centers without high-performance computing resources—the entire platform was compiled into a lightweight standalone executable. This executable integrates all modules (image generation, voice synthesis, and animation) into a streamlined workflow, eliminating the need for installation of external dependencies.

Instead of building a full graphical user interface (GUI), the project opted for a command-line interface (CLI), for three primary reasons:

- Reduced resource consumption: GUI frameworks typically introduce additional memory and processing overhead, which could hinder performance on mid-range consumer hardware.
- Simplified distribution and portability: A CLI application can be deployed easily on devices with limited storage or operating system customizations, such as recycled desktops common in community centers.
- Transparency and replicability: For engineering and technical education contexts, CLI-based tools expose the execution logic more clearly, helping learners understand model orchestration and system flow—key learning goals in AI and software development curricula.

To manage the complexity of AI dependencies (e.g., PyTorch, TensorFlow, Librosa), each module was isolated in its own virtual environment using Conda and Python's native venv system. This approach follows best practices in modular software engineering (Sommerville, 2015), reducing library conflicts and improving the system's maintainability.

During field deployment, CLI commands were simplified with predefined templates and example scripts, enabling even users with minimal digital literacy to generate full video lessons. In a pilot workshop, a group of local mobilizers with no prior experience in Python or CLI environments were able to complete the video generation pipeline independently after a brief 15-minute orientation.

This lightweight, CLI-based distribution model reinforces the project's commitment to inclusive, low-barrier educational technology, and provides a foundation for future integration into broader digital literacy and engineering training programs.

3.5 Program execution

The full execution pipeline follows a linear, modular structure, visualized in the flowchart presented in Figure 1. Users begin with script and character selection, followed by sequential processing through image generation, voice synthesis, animation, and video export.

This structured pipeline facilitates transparency in system behavior—an important aspect in interpretable AI systems (Doshi-Velez & Kim, 2017). Furthermore, it enables localized debugging, modular testing, and customization by advanced users, including university students and faculty exploring open-source AI for educational development.

The visual model was designed not only as technical documentation, but also as a learning tool for engineering education, illustrating how AI components can be orchestrated to solve real-world instructional challenges.

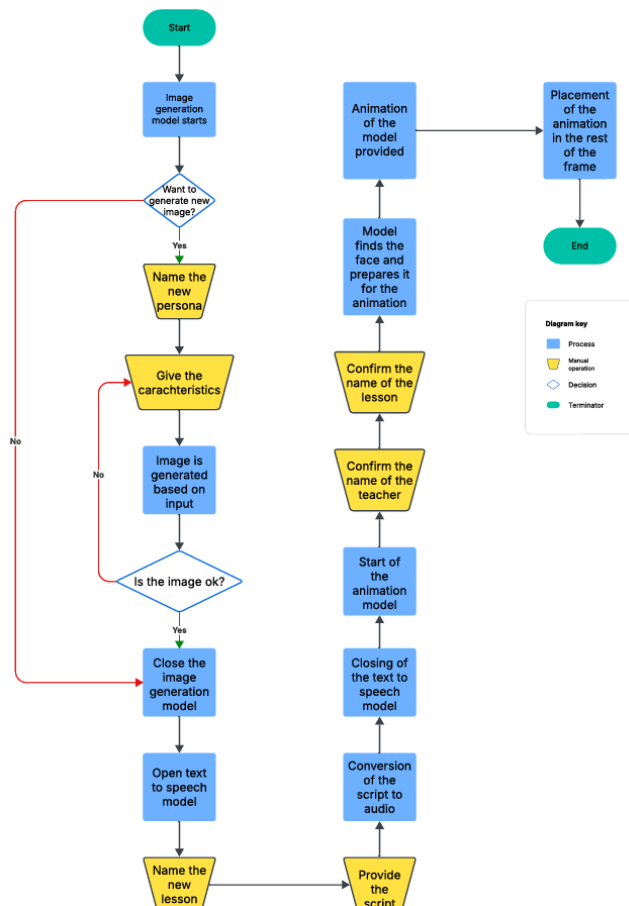


Figure 1. Image of the application Flowchart

3.6 Practical results

As part of the development cycle, the software was tested during field activities carried out under the EDUCADO project and the Digital Mobilizer initiative. These sessions involved direct engagement with waste picker cooperatives and local mobilization teams in Brazil.

During the demonstrations, participants viewed images generated by the system. The personalized avatars were well received, particularly due to their familiarity and expressiveness. Figures 2 and 3 illustrate examples of the avatars used in these sessions. Participants often remarked that the presenters felt relatable, and the natural tone of the speech enhanced comprehension of topics such as occupational health, financial literacy, and proper waste separation.



Figure 2. Woman generated by the software



Figure 3. Man generated by the software

The presence of culturally relevant visual and linguistic features helped foster a stronger connection between the audience and the content, reinforcing the material's accessibility and impact. These initial field impressions confirmed that even in the absence of formal assessment tools, the system effectively supported its educational objectives.

Insights gathered during these sessions led to adjustments in avatar diversity and refinements in the content scripting process, ensuring the platform remains aligned with the real needs and expectations of its users. This phase of testing reinforced the software's potential as both a scalable content generator and a culturally responsive educational tool for underserved communities.

4 Conclusion

The development of this AI-powered content generation platform represents a meaningful advancement in the creation of inclusive educational resources for underserved communities, particularly waste pickers in Brazil. By integrating open-source AI tools for image generation, speech synthesis, and lip synchronization, the system enables scalable, localized video production that operates independently from cloud infrastructure—thereby addressing key barriers related to cost, connectivity, and technical complexity.

Preliminary field testing conducted through the EDUCADO and Digital Mobilizer initiatives demonstrated positive reception from target users. Participants expressed strong identification with the generated avatars, reporting that the familiar speech patterns and expressive visuals made the content more relatable and easier to follow. One waste picker commented that “the instructor looked like someone from our community,” highlighting the social value of personalization. Based on feedback, improvements were made to avatar diversity, voice clarity, and script simplicity to enhance engagement. From an engineering and higher education perspective, this study offers a practical and socially relevant case for integrating ethical, user-centered AI into curriculum and research. It exemplifies how design-based research can bridge theory and practice by combining iterative prototyping, stakeholder feedback, and technological innovation. The solution aligns with educational goals in engineering disciplines by demonstrating how students and professionals can build systems that are technically robust, ethically grounded, and context-aware.

Future work will focus on expanding the system's capacity to support multi-persona narratives, incorporating an AI assistant to support script generation with trusted references, and exploring broader applications in vocational and adult education. Ultimately, this project contributes to both educational access and engineering practice by demonstrating how localized, open AI tools can be used to create high-impact, community-driven learning solutions.

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The Adoption Journey of Active Learning Strategies: reflections from a Brazilian perspective

Andromeda Goretti de Menezes Campos^{1,5}, Dianne Magalhães Viana^{2,5}, Lílian Barros Pereira Campos^{3,5}, Valquíria Villas-Boas^{4,5}

¹ Instituto Federal do Espírito Santo - Campus Cefor

² Universidade de Brasília

³ Federal University of Itajubá – Itabira Campus, Itabira, Minas Gerais, Brazil

⁴ Universidade Federal do Rio Grande do Sul

⁵ Research Group on Active Learning in Engineering Education Working Group (REG-ALE)

Email: liliancampos@unifei.edu.br, diannemv@unb.br, liliancampos@unifei.edu.br, vvillasboas@gmail.com

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Abstract

Adopting active learning strategies can be a difficult decision, filled with apprehension and uncertainties. Various reasons for not adopting active learning strategies are found in the literature, such as fear of additional work, fear of students' reactions, and even concerns about peer evaluation. This paper proposes a discussion on the adoption journey of active learning strategies by a group of Brazilian engineering professors. Therefore, it presents reflections that originated from a focus group session organized by the Working Group on Active Learning in Engineering Education (GTAAEE), held in 2023, during the 51th Brazilian Congress of Engineering Education (COBENGE). The adoption journey of active learning strategies in engineering education developed during the focus group session draws inspiration from a customer journey concept. This paper describes how educators progress through phases such as learning and discovery, recognizing opportunities, considering active learning strategies, adopting these strategies, and eventually publishing their experiences. Additionally, the paper presents the participants' positions within this journey and describes the emotions they experienced, revealing a mix of excitement, fear, loneliness, and eventual awareness of their capacity to balance traditional and active learning strategies. These reflections underscored the non-linear and often overlapping nature of the process, as educators might simultaneously explore new strategies while consolidating others. This paper also discusses key challenges and needs on the adoption of active learning strategies, including the demand for tailored materials, guidance from facilitators, financial support for infrastructure, and more opportunities for collaboration and exchange with peers. This reflection emphasizes the importance of adequate spaces for interdisciplinary dialogue and specific conferences on educational methods to foster a sense of community and encourage engineering education research. The insights of this paper can be explored to create content, to organize events, and to propose actions aimed at supporting educators in overcoming the challenges of adopting active learning strategies in engineering education.

Keywords: Active Learning; Training; Engineering Education

1 Introduction

The adoption of active learning strategies in engineering education is a phenomenon influenced by multiple factors, including governmental guidelines, institutional directives, curricular plans, and broader cultural and contextual aspects. At an international level, initiatives such as the Bologna Process have emphasized student-centered learning approaches, fostering a shift towards more interactive and participatory teaching methodologies. Similarly, in Brazil, the National Curricular Guidelines for Engineering Education (Brasil, 2019) highlight the importance of pedagogical strategies that encourage critical thinking, problem-solving, and collaborative learning, reinforcing the need for active learning in engineering education.

Beyond regulatory frameworks, institutional policies are attempt to foster the implementation of active learning strategies (Grimes & White III (2015). University mandates, pedagogical course plans, and faculty development programs are organized to create an environment conducive to the adoption of innovative teaching methodologies (Eickholt et al., 2019). Nevertheless, cultural and contextual factors—such as resistance

to change, professors fixed mindset (Aragon, Eddy & Graham, 2018), workload concerns (Michael, 2007), and the prevailing perception of traditional lecture-based teaching (Bordel, Alcarria & Cira, 2024) also are some barriers that decrease educators' willingness to embrace active learning practices (Guedes et al., 2023).

The objective of this paper is to present the findings of a focus group session conducted with engineering professors attending the 51st COBENGE conference in 2023. The discussion aimed to explore the adoption journey of active learning strategies, uncovering the motivations, challenges, and emotional experiences associated with this transition. By analyzing participants' perspectives, the study seeks to contribute to a deeper understanding of the factors that facilitate or hinder the integration of active learning strategies in engineering education.

The structure of this paper is as follows: Section 2 provides a theoretical discussion on the adoption of active learning strategies; Section 3 outlines the methodological procedures used in the study; Section 4 presents and discusses the results of the focus group session; Section 5 offers the conclusions drawn from the study; and finally, Section 6 contains the references that support this research.

2 Adoption of Active Learning Strategies in Higher Education: an overview

The adoption of active learning strategies has proven to be increasingly effective, particularly when aligned with learning objectives (Gianesi, Massi & Mallet, 2021) and the need to develop higher-order skills in Bloom's taxonomy (Krathwohl, 2002). These strategies promote meaningful learning (Ausubel, 1968) and encourage students to actively engage in the construction of knowledge (Vygotsky, 1991), fostering complex cognitive skills such as analysis, evaluation, and creation. These competencies are essential for preparing professionals who are not only critical thinkers but also capable of solving real-world problems, especially in engineering—a field that demands not only technical expertise but also the ability to navigate interdisciplinary and innovative challenges (Campos, Pinto & Júnior, 2024).

Despite strong evidence supporting the benefits of active learning methodologies, their adoption faces significant resistance, particularly in engineering education (Grimes & White III, 2015; Eickholt et al., 2019; Aragon, Eddy & Graham, 2018; Michael, 2007; Bordel, Alcarria & Cira, 2024; Guedes et al., 2023). Traditional teaching, which remains predominant in higher education institutions, centralizes the learning process on the instructor, emphasizing linear and predictable content delivery. When instruction shifts to a student-centered approach using active methodologies, instructors may lose predictability in their lessons and direct control over the learning process (William, 2007; Gianesi, Massi & Mallet, 2021). This shift can create uncertainty and resistance, as active teaching requires greater flexibility, continuous adaptation, and a growth-oriented mindset (Aragon, Eddy & Graham, 2018).

The literature identifies several barriers to adopting active learning (Bordel, Alcarria & Cira, 2024). Among these, faculty members' negative perceptions stand out, such as concerns over increased workload and the fear of being perceived by peers as "not working" when implementing these strategies (Guedes, 2023). Additionally, a lack of knowledge about active learning methods and their practical application further contributes to resistance, as many instructors do not feel adequately prepared to use these strategies effectively, leading to a disconnect from innovative pedagogical approaches (Eickholt et al., 2019). Moreover, physical space limitations and a lack of institutional support are also cited obstacles (Guedes et al., 2023).

Silva (2020) understands that, for active methodologies to be effective, it is important that the educator is prepared to modify their teaching and learning concepts, allowing for new ways of interacting with knowledge

and innovative solutions to activities. It is emphasized that perhaps the most difficult change to assimilate is the awareness that certain parts of the content may be sufficient to solve specific problems, while other parts may not be addressed. This rigidity on the part of the professional is also a barrier to the broader and correct use of active methodologies.

William (2007) outlines key barriers to implementing active learning, which are supported by various authors. These barriers can be categorized into student, teacher, and pedagogical challenges. Students often struggle with how to engage in active learning, lack preparation, show reluctance to participate, or demonstrate varying levels of maturity. Teachers face difficulties related to the time required for lesson planning, reduced classroom control, negative perceptions from colleagues, and concerns about student evaluations. From a pedagogical perspective, factors such as inadequate classroom setups, insufficient class time, challenges in assessing students, large class sizes, and unpredictable learning outcomes make active learning harder to implement.

Understanding the variables that influence the adoption of active methodologies in engineering education is essential to overcoming these barriers. Resistance to student-centered teaching and the lack of pedagogical training among faculty directly impact the implementation of these strategies. To effectively promote active learning, it is crucial to establish well-structured faculty training programs and institutional support mechanisms that empower instructors to confidently adopt new pedagogical approaches. This, in turn, fosters the comprehensive development of students, better prepares them for professional challenges, and ensures alignment with curricular guidelines and the evolving demands of the job market.

3 Materials and Methods

This study employs a qualitative, exploratory research design based on a focus group methodology (Krueger & Casey, 2015). Exploratory research is particularly suitable for investigating complex, underexplored phenomena, as it enables researchers to gain insights into participants' perspectives and lived experiences (Stebbins, 2001). A qualitative approach facilitates a deeper understanding of social processes by fostering interactions among participants who share common experiences and concerns related to a specific topic (Krueger & Casey, 2015). Given these advantages, the focus group methodology was selected to explore the challenges and motivations behind the adoption of active learning strategies (Krueger & Casey, 2015).

The focus group session took place on September 18, 2023, during the COBENGE 2023 conference, as part of the Working Group on Active Learning in Engineering Education (GTAAEE). Participants included GTAAEE members and 10 additional attendees representing various Brazilian higher education institutions, such as the Federal University of Rio Grande do Sul, the Aeronautics Institute of Technology, the Federal University of São Carlos, the Federal University of Pará, the Federal University of Itajubá, and the Federal Institute of Espírito Santo. Out of 10 participants, 7 answered the questions made by the focus group organizers.

The session focused on the theme "Adoption Journey of Active Learning Strategies and Methods – Reflections and Proposals for GTAAEE." A structured activity was conducted to identify the different phases of the adoption journey experienced by faculty members and to generate proposals for GTAAEE's future initiatives (2023-2024). The discussion was inspired by the concept of the customer journey, as defined by Lemon and Verhoef (2016). This concept, originally from the Design Thinking approach, maps the experiences consumers have with a brand, from initial awareness to post-purchase engagement.

Based on the customer journey framework by Lemon & Verhoef (2016), which includes five phases—awareness, consideration, acquisition, service, and loyalty—the GTAAEE professors developed a five-phase journey for adopting Active Learning Strategies (ALS). By reflecting on their own experiences in adopting ALS, these professors outlined the typical behaviors that can occur at each phase of the journey. The design of the journey,

resulting from the discussions and reflections of the GTAAEE members, led to the phases described in Figure 1.

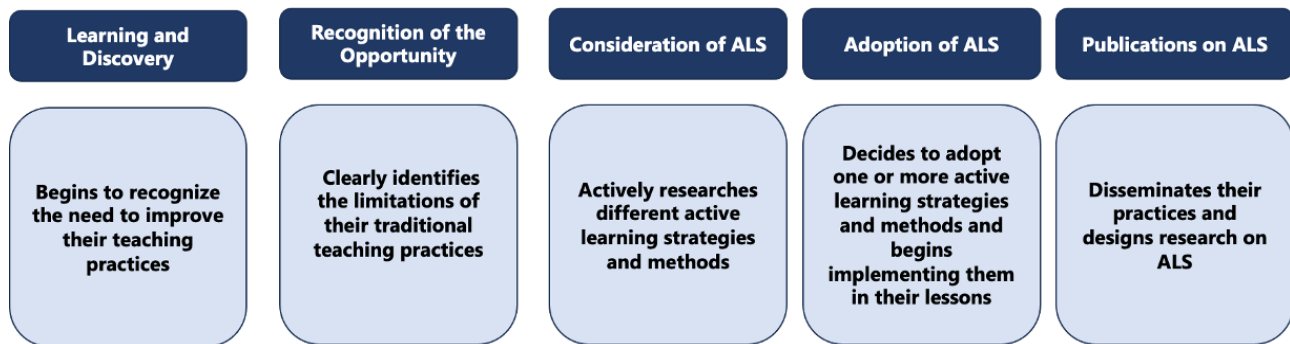


Figure 1: Proposed Adoption Journey of Active Learning Strategies

The proposed Adoption Journey of Active Learning Strategies (ALS) begins with Learning and Discovery, where professors recognize the need to improve their teaching practices. In the Recognition of the Opportunity phase, they identify the limitations of traditional methods and acknowledge the potential of ALS to address these gaps. In the Consideration of ALS phase, professors research various strategies, exploring how they can enhance student engagement and learning outcomes.

Once convinced, professors enter the Adoption of ALS phase, where they implement active learning strategies in their lessons. Finally, in the Publications on ALS phase, professors share their experiences through research and publications, contributing to the academic community and encouraging others to adopt similar approaches. This journey reflects a continuous process of learning, applying, and sharing innovative teaching practices.

Participants were first introduced to the proposed adoption journey of active learning strategy. They were then asked to reflect on their adoption journeys and identify the phase they perceived themselves to be in. Additionally, they were invited to discuss the emotions associated with their experiences, highlighting the complexities and non-linear nature of the adoption process.

Following this discussion, participants were asked to outline their key needs and challenges in adopting active learning strategies. Their responses provided insights into essential support mechanisms, such as access to facilitators, contextualized teaching materials, financial resources for infrastructure, and greater opportunities for collaboration and knowledge exchange among educators.

The data collected during the session were recorded, transcribed, and analyzed qualitatively to identify recurring themes and patterns. This methodological approach ensures a comprehensive understanding of the factors influencing the adoption of active learning strategies, while also guiding the development of targeted initiatives to support engineering educators.

4 Results Discussion

As a result of the focus group organized by the GTAAEE, it was possible to identify three groups of information: 1) the stage of the adoption journey of ALS each participant reported he/she is; 2) the predominant emotions participants have about adopting ALS and 3) the need of support the participants report aiming to generate proposals for GTAAEE's initiatives for the 2023–2024 period.

After the Proposed Adoption Journey of Active Learning Strategies (Figure 1) was presented to the participants, they were asked to identify which stage of the journey they believed they were in and what emotions they

experienced throughout their adoption of AAEE. Table 1 summarizes the accounts collected from seven participants who voluntarily shared the stages of the journey they identified with.

Based on the participants' accounts, it was evident that most respondents perceive themselves as being in multiple stages of the adoption journey of ALS. After a collective discussion, participants agreed that this journey is a cyclical process, with parallel and non-linear phases. In other words, the same professor may simultaneously be discovering a new strategy, considering the adoption of another, and already implementing others. Among the seven respondents, two reported being in an advanced stage of the journey, where they are already able to generate publications on the adoption of ALS

Table 1: Respondents Adoption Journey of Active Learning Strategies Phase - Meeting GTAAEE 2023

Respondents	Learning and discovery	Recognition of the Opportunity	Consideration of ALS	Adoption of ALS	Publications on ALS
1	x		x	x	x
2			x	x	
3	x	x	x	x	x
4			x		
5			x		
6				x	
7	x	x			

Regarding the emotions experienced by respondents throughout their journey, the following situations were reported, as illustrated in the excerpts below:

"I feel both excitement and fear that it won't work." (Respondent 1)

"I feel like I'm alone in a rough sea; it's a solitary job." (Respondent 2)

"In the beginning, I was scared." (Respondent 3)

"I feel aware of what I am doing." (Respondent 4)

"Over time, I understood that it's not about doing everything, but rather integrating what I can into certain content. Some aspects can remain traditional." (Respondent 5)

"Euphoria and fear that it won't work—I don't know how the students will react." (Respondent 6)

As reported by the participants, there is a mix of emotions due to the uncertainty that ALS adopters experience. Many expressed fear and insecurity when facing the challenges of implementing active learning strategies, which leads to a demand for support in overcoming these obstacles.

In response to these concerns, participants were asked what specific needs related to their adoption journey of ALS they would like to bring to GTAAEE. The following demands were identified:

- **Access to facilitators who can assist teachers in moments of doubt** – Professors need knowledgeable mentors or facilitators who can provide guidance and support when they encounter challenges in implementing active learning strategies.
- **Access to materials contextualized by subject or discipline** – Teaching resources should be tailored to specific academic fields, making it easier for educators to integrate active learning into their subject areas effectively.
- **Financial support (e.g., alumni funding) to invest in infrastructure and other needs** – Adequate funding is necessary to improve classroom setups, acquire essential teaching tools, and support other logistical requirements for active learning implementation.
- **Help in dealing with curriculum constraints** – Faculty members require assistance in adapting their courses to accommodate active learning while ensuring alignment with institutional and accreditation requirements.
- **More opportunities for exchange on artistic learning approaches** – Educators seek spaces to explore and share methodologies that integrate artistic and creative approaches into active learning.
- **More spaces for interaction and collaboration among educators** – Professors benefit from structured environments where they can exchange experiences, discuss best practices, and collaboratively address challenges in active learning adoption.
- **Dedicated spaces within subject-specific conferences for education-related work** – Conferences in specialized fields should include dedicated sessions or tracks for discussions and presentations on active learning practices within those disciplines.
- **Access to a learning community to discuss and publish together** – A supportive network of educators can facilitate knowledge sharing, collaborative research, and joint publications on active learning strategies and their outcomes.

Through the interactions in this meeting, it was possible to hear the academic community's expectations regarding ALS adoption. These insights were used to generate content, organize events, and shape GTAAEE's proposed initiatives. These inputs were used to organize a traveling Brazilian symposium, designed to give professors from different regions the opportunity to participate in the events. Additionally, the group has an established practice of annually producing articles and book chapters on the topic. As a future initiative, online content will also be made available through live sessions on the GTAAEE YouTube channel, further expanding support for educators across Brazil. All interaction opportunities are announced via the GTAAEE Instagram, to provide followers with valuable information to assist them on their journey.

5 Conclusion

The findings from this study highlight the complex and dynamic nature of adopting active learning strategies in engineering education. The data collected from the focus group demonstrate that this process is not linear; rather, it involves overlapping phases in which educators simultaneously explore, consider, and implement various methodologies. The emotions reported by participants reinforce the idea that this journey is marked by both enthusiasm and apprehension, with fear and uncertainty often accompanying the transition from traditional to active teaching approaches. Such emotions emphasize the need for greater institutional support, structured professional development, and peer collaboration to ease the adoption process.

Moreover, the barriers identified—ranging from curriculum constraints to the lack of context-specific materials and financial limitations—point to systemic challenges that must be addressed for active learning strategies to be effectively integrated. The expressed need for facilitators, collaborative spaces, and tailored resources

underscores the importance of fostering a strong learning community where educators can exchange experiences, refine their practices, and collectively advance pedagogical innovation.

By incorporating these insights, initiatives such as GTAAEE's traveling symposium, academic publications, and online content creation serve as crucial mechanisms to support faculty in their adoption journey. The continued dissemination of knowledge and expansion of interactive spaces will be essential in ensuring that active learning methodologies are not only embraced but also sustained in engineering education. Addressing these challenges through structured support systems will empower educators, enhance student learning experiences, and contribute to a broader transformation in higher education.

It is important to highlight the limitations of this research. First, this research relied on self-reported data from a relatively small group of participants, which may not fully capture the diversity of experiences and challenges faced by educators in different institutional contexts. Another constraint is the absence of longitudinal data to assess the long-term impact of active learning adoption on teaching practices and student outcomes. Future research should aim to expand the sample size, incorporating a broader range of institutions and disciplines to better understand the factors influencing active learning implementation. Longitudinal studies tracking educators over time could provide deeper insights into how support mechanisms, training programs, and institutional policies affect the sustainability of these strategies. Further exploration into student perspectives on active learning adoption could also offer a more comprehensive view of its effectiveness and potential areas for improvement.

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Integrating DevOps with Problem-Based Learning: Transforming Project Management Education in Computer Science Curricula

Cristiano Jesus^{1,2,3}, Francisco Claro¹, Ivan Amorim¹, Paulo C. Anacleto Filho³, Lúcio Garcia Veraldo Júnior⁴, Sérgio Ivan Lopes^{1,2,5}

¹CiTIn – Centro de Interface Tecnológico Industrial, 4970-786, Arcos de Valdevez, Portugal

²ADiT-Lab, Instituto Politécnico de Viana Do Castelo, Rua Escola Industrial e Comercial Nun'Álvares, 4900-347, Viana Do Castelo, Portugal

³ALGORITMI Research Center/LASI, University of Minho, 4710-057, Guimarães, Portugal

⁴UNIFESP – Universidade Federal de São Paulo

⁵IT – Instituto de Telecomunicações, Campus Universitário de Santiago, 3810-193, Aveiro, Portugal

Email: cristiano.jesus@citin.pt, francisco.claro@citin.pt, ivan.amorim@citin.pt, pauloanacletof@gmail.com, lucio.veraldo@infinityacademy3d.com.br, sil@estg.ipv.pt

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Abstract

This article explores a materialist approach to education, emphasising tangible structures – tools, technologies, and organizational frameworks – in shaping learning rather than focusing on symbolic representations or pre-existing knowledge. We illustrate this by applying DevOps principles in a Project Management course. DevOps, an approach rooted in the material realities of the tech industry (efficiency, collaboration, continuous delivery), integrates development and operations through automation and shared practices. Our teaching-learning experience embedded project planning within the DevOps workflow, using constant feedback and practical, problem-solving projects. Student teams developed, deployed, and monitored systems, reflecting on theoretical foundations during DevOps ceremonies. The final student pitches highlighted the impact of this experience on their academic and professional growth.

Keywords: Problem Based Learning; Active Learning; Project Management; DevOps; Scientific Materialism

1 Introduction

The materialist tradition is interested in observing and analyzing the behavior of structures, whether physical or organizational, and how they are used as resources, rather than focusing on what they mean or how they are represented symbolically. In education, this translates into an emphasis on tools, technologies, architecture and organizational structure, processes and concrete practices that reflect the material conditions of the target agents. In this approach, instead of starting from baselines or knowledge bases as an education strategy, we start from a structure that enables, or even conditions, actions, decisions and practices that are expected and defended by the reference models.

Project Management constitutes a competency that transcends a single scientific domain. Its versatile nature characterizes it, and it applies to virtually all sectors of the economy and the production of goods and services. Due to this broad applicability, its tools and procedures originate from various fields, such as Software Engineering, Civil Engineering, Industry, multiple areas of Communication (including Journalism and Marketing), Health, Education, the Public Sector, the Financial Sector, Commerce, in addition to the core specialties of Business Sciences, such as Management, Accounting, Human Resources, among others.

Thus, Project Management does not rely on static models for problem-solving but rather on a body of scientific and professional knowledge that serves as a reference guide and baseline. As a result, this guide is not applied

literally in any specific case since such conduct would represent an orthodox rigor that is disproportionate and unsuitable to the reality of each project.

This inherent characteristic of Project Management poses a particular challenge to its teaching, as it is essentially a practice-oriented discipline. Therefore, teaching and learning strategies based exclusively on the exhaustive study of concepts, techniques, and models have proven ineffective, tiresome, and demotivating. On the other hand, Project Management does not constitute an unqualified practice in which improvisation is acceptable.

DevOps is an approach that integrates software development (Dev) and technology infrastructure operations (Ops) through tools, automation and collaborative practices. It directly reflects the material conditions of the technology industry, where efficiency, collaboration and continuous delivery are essential, as well as a culture geared towards these values. DevOps is not just about tools and procedures, but about how, integrated into a process, they promote teamwork, efficient communication and continuous improvement, essential skills for any engineer.

This article presents a successful case of teaching-learning experience in Project Management in which planning was treated as one of the functions in the DevOps workflow, seamlessly integrated with the other functions through permanent and transparent feedback. Through practical, problem-solving-oriented projects, student teams adopted and applied procedures reflecting the essential theoretical foundations to develop, deploy and monitor systems. Reflections on these fundamentals were discussed during the planning cycle ceremonies, in sprint review and sprint retrospective meetings. At the end, the students presented pitches in which they expressed the results of this experience on their academic and professional journey.

The case presented in this article was developed in the third year of the Computer Networks and Systems Engineering program at the Polytechnic Institute of Viana do Castelo. Based on philosophical assumptions of materialist orientation, the initial hypothesis (Hypothesis 1) was that a material production structure is a prerequisite for implementing theoretical-practical educational activities in the Project Management discipline. For this purpose, a DevOps platform was selected as the most suitable framework (Hypothesis 2), considering that future professionals trained in this program will presumably work in multifunctional teams dedicated to technological development, involving software and computational systems, and will, in principle, be responsible for infrastructure—a scenario for which the DevOps philosophy is fully aligned. The experience was a success, as will be demonstrated in the quantitative and qualitative evaluation of this case.

2 Theoretical Framing

Among the various approaches in the discussion about the appropriation of knowledge, at its most fundamental bases in ontology and epistemology, the materialist worldview presupposes the existence of a primary reality, called material, which can be observed and verified. In terms of scientific production, logical positivism, atomism, determinism, and objectivism are the central philosophical principles of this view, providing guidelines and methodological tools for the production of scientific knowledge, essentially based on physical reality and experience, within the limits of intellectual analysis, categorization, and conceptualization. Determinism assumes that events are predetermined by the conditions in which they occur, so that they can be predicted and controlled through consciousness and scientific reason (Águila, 2024).

From this perspective, new materialism overcomes the radical duality between matter and observer. It gives way to the vision of reality as an interconnected network in which action is distributed among human and non-human actors, so that reality is considered to be shaped by interactions that substantially challenge conventional notions of causality, evolving from a one-way process to a mutual and reciprocal process in which

entities are both cause and effect of the relationships between them. This position also changes epistemic authority, that is, who determines the validity of knowledge. Material objects do not function as arbiters of scientific claims; instead, in place of absolute correspondence between actions and concept, what matters is what can be observed in the interaction between the social and material aspects of scientific claims, in the result of the dance of resistance and accommodation between material objects and subjects (Tang & Cooper, 2025).

Aligned with this idea, now more specifically regarding technology, based on philosophers who thought about technology such as Martin Heidegger, Jacques Ellul, and Lewis Mumford, Achterhuis (2001b) states that technology should not be thought of as applied natural science, but rather as a “system,” because it is more a way of life than an instrument. In the view of these philosophers, the traditional, and so to speak, naive, view of technology assumes that it is simply the practical application of scientific discoveries. Still, it has its logic, independent of science. Technology shapes science as much as it is shaped by it, because it reorganizes human existence and redefines our way of being in the world. Thus, modern technology is not a helpful tool, but rather a mode of existence, an interdependent network where techniques, institutions, and values mutually reinforce each other, obeying a systemic logic and establishing power relations, because they are intrinsically integrated into social systems, therefore, it is not controllable by individuals, and cannot be assimilated as knowledge in a totalizing way (Tijmes, 2001).

This conceptual and epistemic evolution challenges the understanding of engineering, the role of the engineer, and consequently, the training of engineers, that is, engineering education. Gunay (2018) states that engineering is the practical and creative application of scientific principles to design, develop, and build structures, machines, equipment, manufacturing processes, and specific functions economically and safely. It uses science, mathematics, and design, essentially a problem-solving activity. The engineer transforms ideas into projects and, through technology, into physical products, acting simultaneously in the virtual world (ideas and scientific principles), in the intangible world (projects), and in the tangible world (real products) (Bulleit et al., 2014; Gabbay et al., 2009).

However, as we have seen, interventions in these worlds are not simply mechanical. Therefore, they are mediated relationships. Especially in the training of engineers, one particular challenge must be noted, which concerns the evolution of the nature of the product delivered by engineers (Bulleit et al., 2014). According to Tijmes (2001), modern technology differs from traditional technology because it aims to produce devices, instead of things. Devices are technological means without context, while things are socially embedded. For example, a faucet is a device, and a well is a thing. Unlike the faucet, the well requires familiarity with its machinery and operating conditions. Human involvement and interaction with reality are greater in handling the well than with the faucet. Therefore, modern technology is modeled based on a specific pattern that consists of a device that separates ends and means. The means form the hidden machinery, configured to produce the end safely, easily, instantly, and ubiquitously (Davis, 1998).

Therefore, to think about engineering and the training of engineers, it is necessary to consider the process of instrumentalization, which according to Achterhuis (2001a), is how a technical artifact becomes a usable instrument in society. According to the author, this involves forms of objectification and subjectification associated with a functional relationship with the world and consists of two levels. On the first level, four moments of technical practice occur: (1) Decontextualization, in which the natural objects are removed from their original contexts (e.g., extracting a tree from a forest for carpentry); (2) reductionism, in which decontextualized things are reduced to aspects that can be integrated into a technical network; (3) autonomization, in which the technical actor operates in isolation, minimizing environmental feedback (e.g., consumers in supermarkets lacking knowledge of production processes); and (4) positioning, in which Humans

are categorized functionally, either as labor or consumers. At this level, modern technology organizes the world into a structured, calculable system where elements are primed for technical manipulation. On the second level, it also includes four moments: (1) Systematization, in which technical objects are coordinated into systems and reintroduced into environments; (2) mediation, in which the aesthetic and ethical considerations are embedded into technical objects; (3) vocation, in which work environments are designed to align with workers' professional and personal engagement; finally (4) initiative, in which users adapt technical systems through creative or innovative applications..

Another way of looking at this process of the relationship between human beings, technology, and the world is through their mediators, and in what matters to engineering and engineering education, through the act of appropriating this process, which in theory, is what is supposedly expected of the engineering professional. According to Verbeek (2001), each of the stages of mediation and appropriation marks a specific form of experience and intervention, namely, (1) unmediated perception, in which the subject interacts directly with the world, resulting in immediate, empirical experience that is not shaped by instruments or concepts; (2) mediated perception, which technology acts as an intermediary, enabling the subject to pursue specific goals and transforming the relationship with the world into an instrumental one; (3) incorporation relations, in which technology becomes an extension of the subject, forming a hybrid agent that expands the subject's capacity for action and perception (e.g., using glasses); (4) hermeneutic relations, which the subject adopts an interpretive stance, where technology not only mediates but also reveals or translates aspects of the world (e.g., maps or scientific instruments); (5) alterity relations, in which technology is recognized as an autonomous agent capable of interacting with and altering the world in ways beyond the subject's direct control; finally (6), background relations, in which technology becomes integrated and almost invisible in daily life, forming a backdrop for human activity (e.g., automatic heating systems), so that the environment is experienced as a technologically mediated whole rather than through explicit manipulation of devices.

Therefore, materialist orientations converge toward the view of technology and engineering products as forms belonging to social organization, so the realization and maintenance of concrete social structures consonant with objective reality and rooted in our interaction with materiality is a prevailing factor for our development as human beings and professionals. Our connection with material things in the physical world fundamentally defines our understanding of nature and our relationship with it. As such, materiality cannot be marginalized in education and professional training to privilege the role of pure thought and knowledge at the secondary level of the language structure. In education, both material structures and the worldliness of the individual are starting points for the evolution of consciousness (Korte et al., 2022; Tang & Cooper, 2025).

2.1 Problem-Solving Approach

Constructivism, grounded in the works of Piaget, Vygotsky, and Dewey, is a theory of knowledge and an educational approach that understands learning as occurring through the active construction of knowledge by the student, based on experiences and social interactions. The teacher's role is to mediate and create environments that foster investigation, experimentation, and reflection, making the student the protagonist of the learning process (Evedi & Verawati, 2021; Zaccaria et al., 2025). Therefore, student-centered approaches, active learning, integration of technologies, development of socio-emotional, cognitive, and non-cognitive skills (Rulida et al., 2024), and the importance of collaborative and reflective environments are fundamental for shaping engineers who can act consciously and critically in the modern world, where technology is intrinsically and transparently embedded in reality (Akolekar et al., 2025; Domínguez-Valerio et al., 2025; Gujarati et al., 2025). These trends aim to prepare students for complex challenges by promoting autonomy, creativity, critical thinking, and the ability to solve problems in real-world contexts (Epstein et al., 1996; Kilmann & Thomas, 1977).

Active methodologies originated in health courses, especially in medicine. Still, today they are widely used in STEAM education, an approach that integrates the areas of Science, Technology, Engineering, Arts, and Mathematics (El Fathi et al., 2025). These methodologies provide interdisciplinary, collaborative learning based on practical projects, encouraging students to solve real and complex problems by combining knowledge from these fields (Cline & Powers, 1998; López-Silva et al., 2025; Ramos-Mejía & Padilla, 2025). Several active methodologies that emphasize problem-solving through relationships with the environment and with people are widely recognized by the scientific community, including (Hmelo-Silver, 2004; Kizhukarakkatu, 2025; Naveh et al., 2022; Wood, 2003):

- Problem-Based Learning (PBL): Focused on the collaborative resolution of authentic and open-ended problems, promoting autonomy, critical thinking, knowledge retention, and social skills;
- Project-Based Learning (PrBL): Long-term interdisciplinary projects in which students explore complex topics, connecting theory and practice in real-world contexts;
- Inquiry-Based Learning (IBL): Learning based on investigation, where the emphasis is on the process of discovery and experimentation guided by essential questions;
- Design Thinking: A creative and iterative process for solving complex problems, stimulating innovation, creativity, and critical thinking;
- Experiential Learning: Learning through direct experience, valuing reflection on practice;
- Collaborative Learning: Working in small groups, promoting positive interdependence, individual responsibility, and the development of social and cognitive skills;
- Argumentation: Development of informal reasoning and discourse skills, which are fundamental for building scientific knowledge;
- Multiple Intelligences: Considering different learning styles and valuing skills beyond traditional verbal and mathematical abilities.

The above mentioned methodologies should not be applied as simple laboratory exercises with predictable paths and previously calculated outcomes (Maheshwari et al., 2025). In light of reflections on scientific materialism, it is essential to consider that these methodologies must be guided by principles that promote structured freedom based on concrete foundations, strategically constructed and oriented toward specific goals by experienced teachers (E. Crawley et al., 2014; E. F. Crawley et al., 2014; Laursen & Ryberg, 2025). In this way, they foster the progressive construction of knowledge through problem-solving and challenges based on scientific and professional frameworks, also promoting student engagement, since active involvement, curiosity, and motivation are essential dimensions for strengthening this commitment, a fundamental element for learning (Canavan, 2008; Tjiparuro, 2025; Zhao, 2025).

2.2 DevOps and Project Management in the Context of Software Development and Computational Systems

DevOps emerged to eliminate barriers between development and operations, promoting collaboration, automation, and continuous integration to accelerate delivery and increase system reliability (Chen & Suo, 2023). DevSecOps expands this scope by integrating security practices from the beginning of the software lifecycle (Akbar et al., 2025). The DevOps approach is based on the pillars of Culture, Automation, Measurement, and Sharing (CAMS) (Sravan et al., 2024); therefore, it is seen both as a set of agile practices and as a cultural movement, fostering collaboration among teams, process automation, and continuous value delivery (Wiedemann et al., 2023). Thus, DevOps functions as an engineering platform encompassing infrastructure, processes, relationships, and values, serving as a complete ecosystem for project management (Al-Nakeeb et al., 2024). In this context, the engineer responsible for project management finds an efficient structure, which

incorporates even elements of the Theory of Restrictions (ToC) (Kendrick, 2023), for integrating teams, managing human resources, communication, scope, schedule, risks, quality, and costs, with specific guidelines and tools for each knowledge area to ensure both horizontal and vertical integration across all of them (Akbar et al., 2024; El Khatib et al., 2024).

Agile methodologies are revitalized within DevOps (Beard et al., 2024). Their fundamental principles— iterative development, continuous feedback, and cross-functional collaboration—enable ongoing transformation and adaptation (Kopare et al., 2025). Instead of requiring constant buy-in, self-monitoring, and motivation from Scrum Masters, these principles become structurally embedded in the relationships among the various stakeholders involved (Sravan et al., 2024). With DevOps, transparency, open communication, and collective problem-solving are not just rules to be followed, but rather the active and inevitable dynamic of these relationships. The evolution of agile management and automation tools keeps pace with the need for rapid adaptation, process integration, and data-driven decision support, fitting comfortably within the dynamic nature of projects and facilitating workflow integration, collaboration, and real-time monitoring (Wiedemann et al., 2023). Implementing DevOps and agile methodologies transforms technical processes and organisational culture, promoting empathy, cooperation, real-time communication, and a focus on continuous improvement. Using digital platforms and automation, enhanced by DevOps, facilitates the integration of business areas, processes, and technology while reducing costs (El Khatib et al., 2024).

Therefore, DevOps has the potential to be an essential ally in the transition from traditional educational environments to agile practices, as it is a controlled ecosystem with broad possibilities for technological and relational exploration, as well as offering opportunities for the development of multifunctional (T-shaped) skills and exposing students to practical and iterative scenarios, preparing them for dynamic work environments (Beard et al., 2024).

DevOps is not only a material and technological platform for integrating and running software applications; it also structures the entire process of planning, developing, and deploying software. This structuring significantly defines the standards adopted and disciplines the collaboration among the various stakeholders involved. As an educational strategy for project management instruction, DevOps serves as a controlled microcosm for applying concepts and fostering collaborative relationships. This objective aligns with both materialist and constructivist approaches to education, as it enables experiential learning and the development of practical skills in a real-world, iterative environment.

3 Learning Methodologies, Strategies and Assessment Methods

The Project Management course, an integral part of the Computer Networks and Systems Engineering program at the Polytechnic Institute of Viana do Castelo, is taught in the third year of the students' academic path. The program aims to train professionals with competencies in Computer Programming, Applications and Services, Network and Communications Engineering, Systems Engineering, Systems and Network Administration, Network Design, Project Management, and Consulting in Networks, Systems, and Security. The graduate profile is predominantly oriented towards information technology infrastructure, encompassing software and computer systems programming skills.

The Project Management course unit aims to equip students with the knowledge, skills, and abilities necessary for effective involvement in the planning, execution, monitoring, and evaluation phases of software projects in various organizational contexts. At the same time, it seeks to raise students' awareness of the theoretical frameworks of Project Management and the application of agile methodologies.

The case presented in this article was developed during the first semester of the 2024/2025 academic year, corresponding to the period between September 2024 and February 2025. As active learning strategies, Problem-Based Learning (PBL) methodologies were employed, supported by collaborative learning techniques and oriented towards developing multiple intelligences. These strategies were aligned with interpersonal skills and soft skills essential to project management, as established in the Individual Competence Baseline for Project, Program, and Portfolio Management of the International Project Management Association (IPMA). Among these competencies are: self-reflection and personal management, integrity and reliability, interpersonal communication, relationship and commitment, leadership, teamwork, conflict and crisis management, resourcefulness, and negotiation.

Before addressing the technical content of Project Management, students were introduced to the fundamental concepts of DevOps, including its structure, objectives, involved technologies, and the production systems it targets, covering topics such as enterprise architecture, software architecture, methodologies, procedures, and tools.

The challenge proposed to students consisted of implementing an on-premises DevOps platform for a software development laboratory within a non-profit Technology and Innovation Center, primarily funded by publicly financed projects aimed at innovation and technology transfer. A particularly critical aspect of this scenario is the highly volatile nature of the services provided, which are always linked to time-bound funded projects.

The 38 students were introduced to essential concepts and encouraged to deepen their understanding using the visual tool Process Model Canvas (PM Canvas), applying concepts such as SMART Objectives, scope, requirements, Work Breakdown Structure, risks, costs, and more. They organized themselves into nine teams, self-assigning roles such as Project Manager, Scrum Master, Product Owner, and Developers. They also developed a stakeholder management plan based on a RACI matrix (responsible, accountable, consulted, and informed). These initial actions resulted in the creation of the Project Charter document.

In response to the specific challenge of the fictional scenario, especially regarding the critical aspects of funding sources and the mission of technology transfer, students were prompted to develop a rationale for the acceptance criteria of the technological tools to be adopted for the DevOps platform. They concluded that the tools should meet the following requirements:

- The tool must be open source, given the organization's mission of technology transfer;
- The tool must be a community edition, as it should constitute an on-premises platform, and the team should foster a sense of collaboration for innovation and technological advancement;
- The tool must have a self-hosted option, since cloud versions may be adopted if there are ongoing funded projects with a budget for this purpose. However, upon their conclusion, all results must be reproducible on the organization's infrastructure.

Based on these criteria, the teams conducted extensive research, the results of which are concisely presented in Table 1.

Students were provided with tutorials and technical guides for installing and integrating all tools within a DevOps platform based on Kubernetes or Kubernetes distributions such as Microk8s, K3d, Minikube, and Kind.

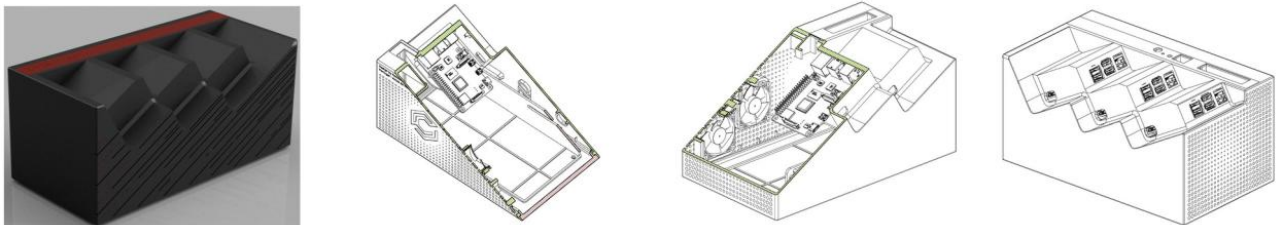
Table 1: Tools according to acceptance criteria

Tool	Open Source*	Self-Hosted*	Community Edition*	Eligible*
Openproject	Y	Y	Y	Y
Trello	N	N	N	N
Clickup	N	N	N	N
Taiga	Y	Y	Y	Y
GitHub	N	N	N	N
GitLab	Y	Y	Y	Y
Jenkins	Y	Y	Y	Y
Sonarqube	Y	Y	Y	Y
AWX & Ansible	Y	Y	Y	Y
ArgoCD	Y	Y	Y	Y
Prometheus	Y	Y	Y	Y
Grafana	Y	Y	Y	Y
Google Drive	N	N	N	N
Nextcloud	Y	Y	Y	Y
Google Docs	N	N	N	N
Collabora	Y	Y	Y	Y

*Yes (Y), No (N)

Given the context of resource management and the constraint of having no financial budget for the course, students were challenged to identify alternative solutions for provisioning the platform. They researched a range of options, from widely known providers such as AWS, Microsoft Azure, Google Cloud, Oracle Cloud, and IBM Cloud, to other platforms offering limited but suitable free resources for educational purposes, such as Oracle Cloud Free Tier, KodeKloud Hands-On Labs, and iximiuz Labs. Some teams chose to create clusters using their equipment. In contrast, with voluntary support from an Industrial Designer and through self-funding, one team developed a cluster using Raspberry Pi devices and 3d printing, as illustrated in Figure 1.

Figure 1. Raspberry Pi Cluster



The cluster setup includes four Raspberry Pi 5 devices, each with 4GB of RAM, memory cards, and heat sinks, as well as an industrial power supply. With the addition of a 3D-printed case made from PLA filament, the total investment amounted to 351.83€. With this configuration, high availability and load balancing cannot be guaranteed. These limitations sparked discussions among the students, prompting them to explore and better understand the concepts and requirements necessary to implement such features.

The students transformed the challenge into projects by creating epics, user stories, tasks, and kanbans. They developed sprint strategies and conducted sprint review meetings, sprint retrospectives, and backlog refinement sessions, with the teacher assuming the role of the client. The projects were presented in two stages. The intermediate presentation served to correct approaches and prepare for the final presentation.

For the individual component, students created a five-minute video pitch in which they reflected on their experiences, describing the barriers they encountered and the value they identified in the course and its format. Assessment was based on students' progress in teamwork, approach to technical challenges, commitment, and individual development.

The course had 38 students enrolled. Six students neither attended classes nor participated in any activities. Two students chose not to complete the assigned activities and instead took the exams, achieving the minimum passing grade. Among the students who actively participated, only three received the minimum passing grade because they did not submit the pitch video assignment; the rest scored between 15 and 18 out of a maximum of 20. As a result, the overall pass rate was 84.2%.

4 Conclusion

A general sense of satisfaction could be observed through the video pitches produced by the students. Most students had never heard of the DevOps philosophy, and their previous understanding of project management was limited to a simple to-do list.

Given the challenging task of implementing a complex platform such as DevOps, all teams sought external assistance from individuals with experience in the field. This engagement significantly contributed to raising students' awareness and motivation, as they realized firsthand that DevOps is a highly sought-after and relatively scarce skill in the job market, which could serve as a distinguishing factor for them.

However, some constraints were identified. One student, who demonstrated clear leadership qualities and thus was influential among peers, was initially critical and resistant to the course format, expressing a preference for a traditional, lecture-based approach. This student did not initially see the value in a platform requiring the integration of many tools and felt that project management was not adequately addressed in a course dedicated to this subject. Nevertheless, as the project progressed and the initial installation and configuration phases were completed, the student understood and embraced the proposed strategy. In their pitch, the student acknowledged the value of all the competencies developed.

Another challenge was related to the formal structure of the course and institutional regulations. Some students chose to take exams and resit assessments after the regular assessment period, thereby opting out of the proposed project-based evaluations. For these students, it was necessary to develop traditional tests, and their evaluation was based on the core content of project management as an area of knowledge.

Acknowledgments

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Disclosure of Interest

The authors report there are no competing interests to declare.

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World Café Dynamic: active learning to address Quality Tools

Lucio Garcia Veraldo Junior^{1, 2}, Cristiano Jesus^{3, 4, 5}

¹ Universidade Federal de São Paulo, Brazil.

² Infinity Academy 3D, Brazil.

³ CiTin – Centro de Interface Tecnológico Industrial, 4970-786, Arcos de Valdevez, Portugal

⁴ ADiT-Lab, Instituto Politécnico de Viana Do Castelo, Rua Escola Industrial e Comercial Nun'Álvares, 4900-347, Viana Do Castelo, Portugal

⁵ ALGORITMI Research Center, School of Engineering, Production and Systems Department, University of Minho, 4800-058, Guimarães, Portugal

Email: lucio.veraldo@infinityacademy3d.com.br, cristiano.jesus@citin.pt

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Abstract

Operational Excellence is a fundamental pillar for the competitiveness of industries and services, promoting process optimization and waste elimination. In the context of higher education, the adoption of active methodologies enhances learning and the practical applicability of theoretical concepts. This study presents a didactic experience based on the World Café dynamic to address the Seven Quality Tools, providing students with an in-depth and interactive understanding of quantitative waste analysis, project management, and decision-making based on indicators. The World Café was employed to stimulate knowledge exchange and co-creation of solutions, allowing participants to move between different discussion groups and explore content from multiple perspectives. The results demonstrated that the methodology fostered greater engagement and knowledge retention, facilitating the understanding of quality tool applications in continuous process improvement. Additionally, the approach enabled students to identify real improvement opportunities and propose technological solutions grounded in scientific principles, bridging theory and practice. This experience reinforces the potential of active methodologies in teaching Operational Excellence applied to Technological Innovation, highlighting that the use of interactive dynamics can be a differentiator in training professionals capable of leading improvement and organizational transformation projects. The research will serve as a foundation for future investigations into the integration of active methodologies in education for industry and services, promoting more effective teaching aligned with market needs.

Keywords: World Café; Quality Tools; Active Learning; Operational Excellence.

1 Introduction

The World Café is a way of creating meaningful dialogues in an organization. Since organizations often need to involve many people in the creation of knowledge, the ambition of the World Café is to reach an area of collective intelligence that has been forgotten in the individualistic cultures of today. The method is based on a belief that there is a field of wisdom which can be reached in groups, but which is usually inaccessible for individuals (Brown & Isaacs, 2005).

Quality tools are important instruments to ensure the continuous improvement of a company's production process. Lobo (2020) states that "quality tools are a first step towards improving process profitability through the optimization of operations." Among the most used tools are the Ishikawa Diagram (known as a herringbone or cause and effect diagram), 5W2H, Histogram, Pareto Diagram, Check Sheet.

Such tools aim to increase efficiency, reduce costs and minimize errors in a process or product. Given this, it is essential to remember that some tools mentioned above do not have a difficult form of applicability as Souza (2018) says "to various quality tools, such as the 5S, CCQ, the 5W2H, cause and effect diagram, can have

practical application, easy deployment and understanding, and lead organizations to a considerable improvement in quality".

Quality management is another field in which several tools for learning and innovation have been created. Exploring ways of integrating the World Café with these tools should be interesting. The World Café and the quality management tools both have an ambition to contribute to profound learning in organizations (Lagrosen, 2019).

This study aims to explore the effectiveness of the World Café methodology in enhancing the teaching and learning process of the Seven Quality Tools within the context of Operational Excellence. Specifically, it seeks to evaluate how this collaborative and dynamic approach supports students in understanding key concepts such as waste analysis, project management, and data-driven decision-making. Additionally, the study examines the extent to which the interactive group format fosters student engagement and encourages the development of practical solutions aligned with continuous improvement initiatives.

2 Active Learning – World Café

Active learning has been broadly defined as a type of learning that demands active gathering, processing, and application of information rather than passive assimilation of knowledge (Bonweel & Elison, 1991). This form of learning is well aligned with principles of adult learning, including self-direction, purposefulness, experience-based, ownership, problem orientation, mentorship, and intrinsic motivation (Knowells, 1984).

World Café's have been shown to be useful as a qualitative research method for exploring the viewpoints of many people to create value that is significant. For instance, the method has been used for studying service development and workplace learning in British healthcare (Peddler & Abbot, 2008).

According to Da Silva (2023), a significant feature of the World Café methodology lies in the agility and fluidity among teams, allowing participants to move across multiple groups and examine a given topic from diverse perspectives. As the activity progresses, the initially defined groups begin to diversify, thus ensuring the continuous circulation of ideas and fostering a richer collective understanding.

Brown and Isaacs (2007) emphasize that this methodology enables the connection of various themes around a central topic. This is made possible by the participants' movement across discussion tables, which allows for the formulation of opinions based on the topics previously debated by other groups. Furthermore, according to the authors, active listening to the guiding question, engagement with the perspectives shared by preceding groups, and the ability to connect emerging ideas are essential elements of what is referred to as the "World Café Etiquette," as detailed in Figure 1.

A basic assumption of the World Café is that people have within them the creativity and wisdom that is needed for solving all kinds of problems, even the difficult ones. Discussing in small groups and then spreading the insights to larger groups creates a self-enhancing meaning-creating network. The combination of gathered attention and collective reflection enables the participants to sense patterns, deeper questions and insights into what the heart of the matter is. A kind of wholeness appears in the gap between the participants. World Café's are supposed to be suitable (Brown & Isaacs, 2005)

- for an in-depth exploration of the main challenges and possibilities.
- for sharing knowledge, stimulating innovative thinking and building community.
- for creating a rewarding interaction between speakers and the public.
- if the number of participants is larger than twelve (without any upper limit); and
- if you can spare at least two hours (and up to several days).

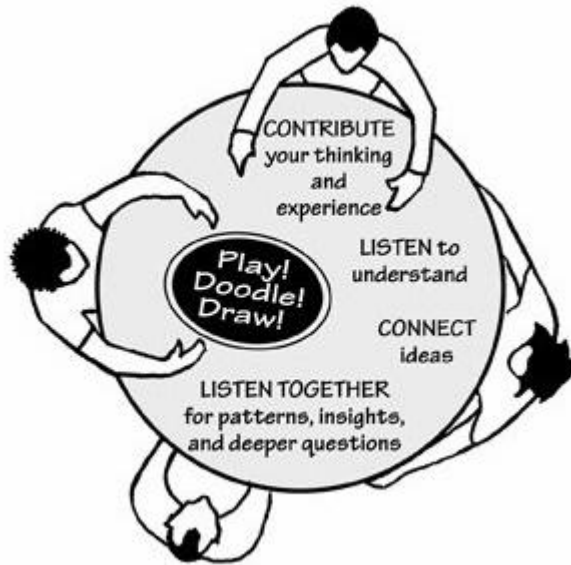


Figure 1. World Café Etiquette. Source: <https://www.itcilo.org/methods>

According to Brown (2001), the physical environment selected for welcoming participants must be warm and inviting, with the aim of creating a safe space where everyone feels comfortable. Establishing such an atmosphere is essential to fostering open dialogue and collaboration. Additionally, formulating relevant and thought-provoking questions can yield highly effective outcomes by promoting active participation and engagement. As participants rotate between tables, they are encouraged to contribute meaningfully to the exchange of ideas, key concepts, and thematic insights. This dynamic interaction not only facilitates the emergence of new perspectives but also underscores the importance of listening attentively to those insights and ultimately sharing the collective discoveries with the larger group.

3 Methodology Context

The object of study in this research is the undergraduate course "Operational Excellence," which integrates theoretical foundations and practical applications related to performance optimization in manufacturing and service sectors. The course provides a comprehensive overview of key concepts such as process mapping, value stream analysis, waste reduction, project management, and the use of quality tools for continuous improvement. Students are encouraged to engage in real-world challenges, applying methodologies aimed at increasing productivity, efficiency, and competitiveness.

In this context, the course adopts active learning strategies to deepen students' understanding of operational excellence and technological innovation. By emphasizing experiential learning through problem-solving and teamwork, the course fosters the development of analytical skills and decision-making based on quantitative indicators. One of the main pedagogical approaches applied in this study is the World Café methodology, which is used to teach the Seven Quality Tools interactively and collaboratively. This setup provides a dynamic and inclusive environment that simulates real organizational challenges and prepares students to lead improvement initiatives in their future professional contexts.

The World Café is an easy-to-use participative method to organize and facilitate meetings. It helps create a living network of collaborative dialogue and opens a space for the exchange of ideas (Urbact, 2024):

- **WHAT IS NEEDED?**
 - **Time:** 2 hours
 - **Participants:** 4-5 by table
 - **Material support:** workboard + A4 sheet +pens
 - **Define the roles:** ask one person to be the table host while the others will serve as travelers. The travelers carry key ideas, themes and questions into their new conversations, while the table host welcomes the new set of travelers and facilitates the discussion.
 - **Choose your question(s):** find questions that are relevant to the real-life concerns of the group. You may use the same question for one or more rounds of conversation, or you may pose different questions in each round to build on and help deepen the exploration.
- **WHAT FOR?**
 - **To identify patterns.**
 - **To develop collective knowledge:** at the end of the second or third round, all the tables in the room will be cross-pollinated with insights from prior conversations.
 - **To encourage the emergence of possibilities for action:** by providing opportunities for people to move in several rounds of conversation, ideas, questions, and themes begin to link and connect.
- **HOW TO USE IT?**
 - **Step 1:** Seat people at small Café-style tables or in conversation clusters (optimal number is 4-5).
 - **Step 2:** Set up progressive (at least three) rounds of conversation, approximately 20 minutes each.
 - **Step 3:** Engage questions or issues that genuinely matter to the work of the stakeholder group.
 - **Step 4:** Encourage participants to write, doodle and draw key ideas on their tablecloths and/ or note key ideas on large index cards or placemats in the center of the table.
 - **Step 5:** After completing the initial round of conversation, the table host welcomes a new set of travelers.
 - **Step 6:** After at least three rounds of conversation, initiate a period of sharing discoveries & insights in a whole group conversation.

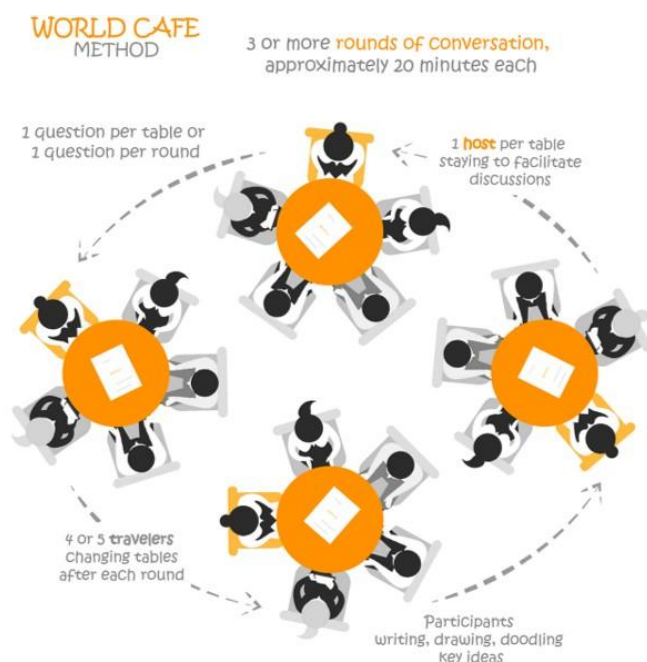


Figure 2. World Café Method Steps. Source: <https://urbact.eu/toolbox-home/analysing-problems/world-cafe>

4 Results and Discussions

The results obtained from the application of the World Café methodology within the context of the Operational Excellence course reveal valuable insights into students' learning experiences and their understanding of quality management tools. The analysis of responses to the structured questionnaire demonstrates a high level of engagement, comprehension, and critical thinking regarding the use of the Seven Quality Tools in real-world scenarios. This section presents the collected data and discusses the implications of the findings, it highlights how the interactive nature of the World Café contributed to knowledge retention, collaborative learning, and the development of practical skills aligned with continuous improvement and technological innovation.

To deepen the interpretation of student responses, this section also presents graphical representations of the questionnaire results, providing a visual overview of the learning outcomes achieved through the World Café methodology. The graphs illustrate the distribution of responses across each question, allowing for a clearer understanding of student perceptions, levels of knowledge acquisition, and the effectiveness of the methodology in fostering critical reflection on the application of quality tools. These visual data support the qualitative analysis and strengthen the evidence of the methodology's impact on the students' educational experience.

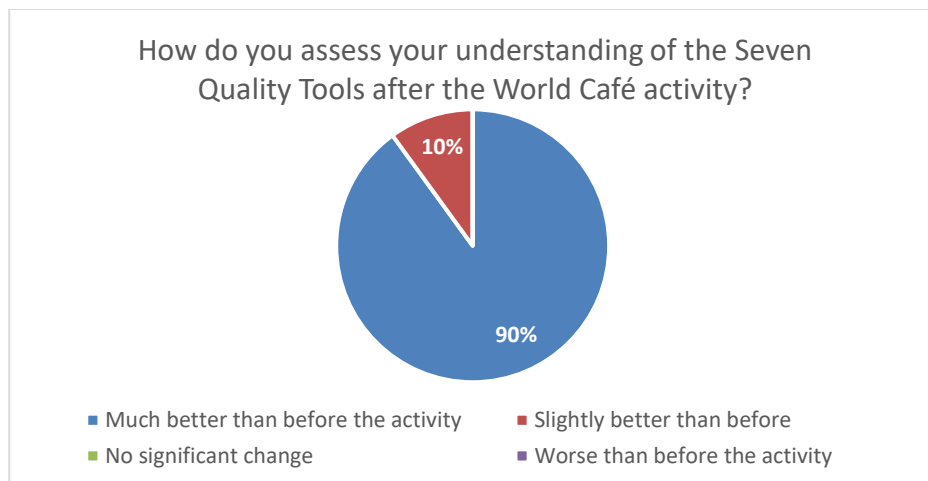


Figure 3. Tools Understood

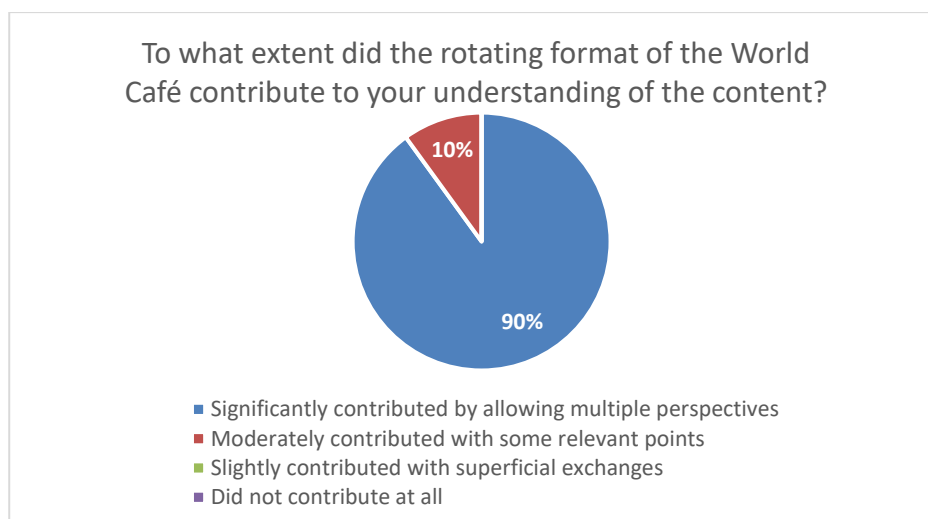


Figure 4. Stimulated Interest

Did the World Café dynamic encourage your active participation and exchange of ideas with classmates?

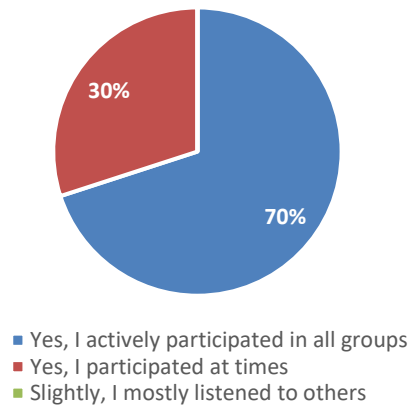


Figure 5. Learning Collaborative

Do you think the practical application of the concepts discussed during the World Café rounds helped reinforce your learning?

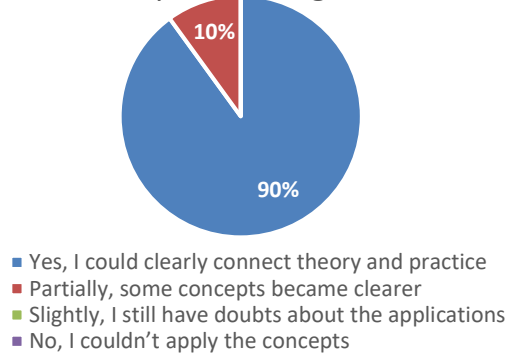


Figure 6. Practical Application

How did the methodology impact your ability to identify improvement opportunities in real processes?

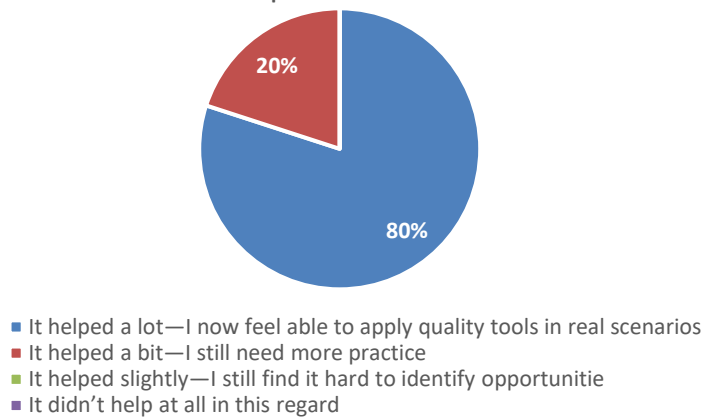


Figure 7. Interpreted Indicators

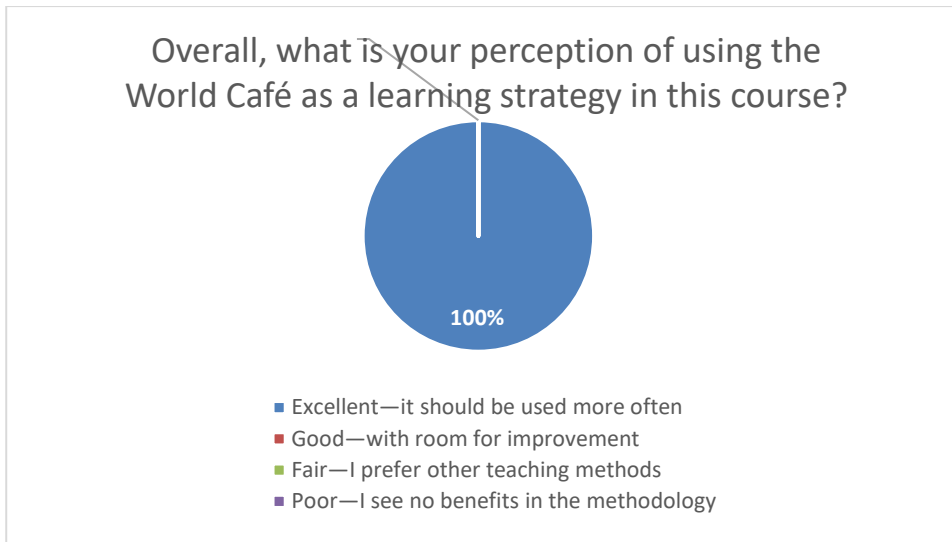


Figure 8. Technological Proposals

The analysis of the questionnaire responses administered to students in the Operational Excellence course reveals the effectiveness of the World Café active methodology in the teaching-learning process of the Quality Tools. The strong predominance of favorable responses (option A) across all questions, particularly in questions 1, 2, and 4 with 90% agreement, indicates that students' conceptual understanding was significantly enhanced following the activity. The dynamic and interactive approach facilitated the internalization of theoretical principles and their practical applications, underscoring the potential of active methodologies in fostering deep learning. Question 3, which addressed students' active participation and engagement in group discussions, showed a slight variation, with 70% of students indicating full engagement and 30% reporting partial involvement. While still predominantly positive, this result suggests the presence of varying levels of comfort and initiative among students when engaging in collaborative environments. This observation highlights the importance of complementary strategies aimed at promoting equitable participation and fostering a safe space for idea-sharing, thereby enhancing inclusiveness and collaboration in academic settings.

The analysis of question 5 shows that 80% of students feel capable of applying the Quality Tools in real-world contexts, indicating effective knowledge transfer from theory to practice. Furthermore, the unanimous agreement (100%) in question 6 regarding the overall effectiveness of the methodology confirms its relevance as an innovative and impactful teaching strategy. These qualitative findings support the premise that the World Café methodology promotes not only collective knowledge construction but also the development of essential skills for solving real-world problems, contributing to the formation of more critical, engaged, and technically proficient professionals.

In conclusion, the data derived from the student questionnaire consistently demonstrate that the implementation of the World Café methodology in teaching Quality Tools constitutes an effective pedagogical strategy for advancing operational excellence in academic contexts. By integrating theory and practice through collaborative dynamics, students were encouraged to develop analytical, participatory, and reflective competencies essential for identifying and addressing real-world issues in productive environments. The high rates of positive agreement across all items reflect not only student engagement but also the consolidation of applied knowledge, reinforcing the role of active methodologies as central instruments for innovation in higher education. This study thus contributes to the academic literature on innovative educational practices by showing that experiential learning, supported by interactive dynamics, enhances the formation of professionals equipped to lead continuous improvement and organizational transformation in industrial and service contexts.

5 Conclusion

The present study successfully met its general and specific objectives by exploring the World Café methodology as a tool to enhance student engagement and understanding of the Seven Quality Tools within the discipline of Operational Excellence. The implementation of this active methodology allowed participants to interact dynamically, promoting collaborative learning and the exchange of diverse perspectives on quality-related themes. This approach directly contributed to a deeper comprehension of theoretical content and its practical applicability in real-world organizational settings.

The results obtained through the applied questionnaire reveal a high level of satisfaction and engagement among students. Over 90% of participants strongly agreed that the methodology facilitated the understanding of quality tools, encouraged critical thinking, and improved their ability to interpret performance indicators. Moreover, the unanimous agreement on the opportunity to propose technological solutions grounded in scientific knowledge reinforces the effectiveness of the World Café in aligning academic instruction with market needs.

The study highlights the importance of active methodologies in higher education, particularly in engineering and management disciplines, where theoretical content must be effectively integrated with problem-solving skills. The World Café dynamic proved to be a powerful instrument for knowledge construction, fostering an inclusive and reflective environment that empowers students to become active agents of organizational transformation. This reinforces the pedagogical relevance of structured, student-centered activities in promoting meaningful learning experiences.

For future work, it is recommended to expand the use of the World Café methodology to other topics within Operational Excellence and to conduct comparative studies involving different educational strategies. Additionally, incorporating digital collaboration tools could enhance the scalability and accessibility of the experience, particularly in hybrid or remote learning contexts. The integration of artificial intelligence to support the analysis of group insights and the proposal of continuous improvement initiatives presents a promising avenue for educational innovation and further research.

Acknowledgments

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Teaching Machine Learning in Production Engineering: Developing Practical Applications for Professional Training

Eugenia Cornils Monteiro da Silva¹, Antônio Augusto Maciel Guimarães², Marcelo Carneiro Gonçalves³, Marcelo Becker⁴, Sanderson Cesar Macedo Barbalho⁵

¹ University of Brasília, Production Engineering and Mechatronic Engineering Departments, Brasília, Brazil.

² University of Brasília, Production Engineering Departments, Brasília, Brazil

³ University of Brasília, Production Engineering and Mechatronic Engineering Departments, Brasília, Brazil

⁴ University of São Paulo, São Carlos School of Engineering, Department of Mechanical Engineering, Mobile Robotics Group – Robotics Lab (LabRoM), São Carlos, Brazil.

⁵ University of Brasília, Production Engineering and Mechatronic Engineering Departments, Brasília, Brazil.

Email: eugeniacornils@gmail.com, 190084421@aluno.unb.br, marcelo.goncalves@unb.br, becker@sc.usp.br , and sandersoncesar@unb.br

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Abstract

Technological advances in Artificial Intelligence (AI), combined with the development of Machine Learning (ML) and Deep Learning models, have revolutionized the job market in engineering and various other professional areas. Given this scenario, it is essential that universities are prepared to include subjects that allow students to understand how these technologies work, since many professions could be transformed or even replaced using these tools. For future professionals to be able to face this new reality, it is essential that they acquire the ability to develop their own AI applications and models. The aim of this paper is to present how Machine Learning is being taught in an Information Systems subject on the Production Engineering course. The methodology adopted emphasizes practical learning, in which students develop their own applications using Machine Learning and AI techniques. As a result, innovative projects have been created, such as sentiment analysis algorithms based on movie rating databases and predictive models for choosing the Oscar winner, among others. In addition to the projects developed, one of the main gains of the course was the students' ability to analyze the results obtained from the data, making their presentations even richer and more interesting. At the end of the course, the students demonstrated an understanding of Machine Learning, but also how these technologies can contribute to their careers and academic lives.

Keywords: Machine Learning; Engineering education, Skills.

1 Introduction

Innovations related to the use of Machine Learning techniques have revolutionized both the job market and the academic environment. Traditional statistical methods, which have been widely developed and applied over decades, have shown inferior results when compared to certain approaches based on machine learning (Garcia Castro et al., 2024). Algorithms such as Random Forest, Decision Tree, Support Vector Machine (SVM), among other classification and regression models, have stood out for their ability to analyze, predict and support decision-making in various contexts (Wang et al., 2025).

Given this scenario, there is a clear need for students to be prepared to deal with these new tools and to understand how to apply them in a practical way in the field of Production Engineering. This need is intensified by the growing demand from organizations for technological innovations that guarantee greater competitiveness, cost reduction and increased market share. Companies that fail to adapt to these technologies tend to lose relevance and efficiency in their processes.

Nowadays, a huge amount of data is generated continuously in the most diverse productive and organizational sectors. However, the ability to identify where these databases are available, structure them appropriately for analysis and integrate them into practical applications still represents a significant challenge for many

professionals in the field of Production Engineering. Understanding which data can be extracted from real sources, such as public platforms or internal company systems, as well as the ability to select relevant data to improve the efficiency of production processes, is a strategic competence. At the same time, mastery of Machine Learning tools, libraries and techniques that enable the creation of predictive models and decision support systems is essential. The right choice of these tools, combined with the intelligent use of databases, can lead to significant gains in productivity, quality and competitiveness in the business environment (Al-Fakih et al., 2024; Garcia Castro et al., 2024; Gürdür Broo et al., 2022; Leung et al., 2008; Wang et al., 2025).

Although there are relatively old studies addressing the use of Machine Learning in engineering education, there is still a significant gap in the adoption of more effective methodologies that truly encourage students to integrate these tools into their technical training and future professional practice. Many of the existing works are limited to presenting generic concepts or applications, lacking a pedagogical approach that actively engages students or motivates them to develop data-driven solutions. Therefore, there is an urgent need to design more engaging educational practices that connect theory and practice, and that promote the strategic use of machine learning algorithms to address real-world engineering problems.

This work aims to introduce students, in a practical and didactic way, to the main fundamentals of Machine Learning, from searching for relevant databases to extracting information and generating applicable insights. The proposal includes identifying problems, organizing data, generating context, and applying machine learning algorithms to obtain interpretable and relevant results. The approach is grounded in Problem-Based Learning (PBL) and active learning methodologies, encouraging students not only to listen and understand theoretical concepts but to apply them in real-world contexts. Based on Bloom's Taxonomy, this strategy promotes higher-order thinking by enabling students to analyze, evaluate, and create, thus developing their cognitive abilities and enhancing their capacity to use these tools in both academic and professional settings. In the next section, the methodologies used will be described, followed by a presentation of the projects developed by the students based on the activities carried out in the classroom (Dolog et al., 2016).

2 Methodology

The methodology adopted in this study was divided into two main stages. The first stage involved conducting a bibliometric and bibliographic review aimed at identifying how Machine Learning has been taught in engineering programs, particularly in the fields of Industrial Engineering, Manufacturing Engineering, and Production Engineering. For this purpose, a search strategy was developed using specific keywords related to "Machine Learning" and its applications in engineering education ("machine learning" OR "artificial intelligence") AND ("teaching" OR "education" OR "curriculum development" OR "pedagogical strategies") AND ("engineering" OR "industrial engineering" OR "production engineering"). The initial search returned 16,653 articles. A filtering process was applied to select current scientific publications. Initially, a search was carried out without restrictions on the publication year. Then, to ensure the analysis was focused on recent developments, the results were refined to include only articles published in the last five years, from 2021 to 2025. This refinement resulted in a total of 9,991 articles, which were then considered for further examination in this study. This set was then refined to include only publications from the last five years and those classified under the subject areas of Industrial and Manufacturing Engineering, resulting in 248 articles.

The final dataset, composed of 248 articles, was analysed using the Web of Science's integrated bibliometric analysis tools and subsequently imported into the Bibliometrix package for deeper exploration. This dual approach allowed for the examination of several key aspects of the selected literature, including the identification of the most prolific and influential authors, as well as the institutions with the highest number of

publications in recent years. The bibliometric analysis also enabled the observation of collaboration networks—both international and institutional—and the mapping of emerging research trends within the field. Based on these findings, a selection of highly relevant articles was reviewed in full and cited throughout the literature review section, ensuring a solid foundation for understanding the state of the art in this domain

From this refined dataset, the most relevant articles were selected for in-depth analysis of the state of the art, with a particular focus on the teaching methodologies employed, the tools and technologies used, and the strategies for integrating Machine Learning content into Production Engineering curricula. Based on the insights gathered, it was possible to identify best practices, gaps, and opportunities to design a more effective instructional approach. This analysis supported the second stage of the methodology, described in the following section, which presents the development of the lesson plan implemented in the Information Systems course within the Production Engineering program.

2.1 Problem-Based Teaching Strategy for Machine Learning Applied to Production Engineering

Teaching Machine Learning algorithms in the context of Production Engineering is becoming increasingly relevant as companies strive to turn large volumes of data into strategic decisions. This work presents a teaching methodology focused on the practical application of algorithms to real-world datasets, aiming to develop students' ability to extract valuable insights and propose evidence-based solutions. Grounded in research on Problem-Based Learning (PBL) and Active Learning, the approach fosters greater student autonomy in the learning process, encouraging critical and applied knowledge construction. By understanding how the outcomes of these models can support decision support systems, students are prepared to contribute with more robust analyses and more assertive decisions in business environments.

In the initial development of the lessons, students were introduced to the fundamental concepts of Artificial Intelligence (AI), Machine Learning and Deep Learning, contextualizing their applications in the Production Engineering environment. Next, the main categories of Machine Learning problems were introduced, with an emphasis on classification and regression, exemplifying their practical applications in different organizational scenarios.

As part of the active methodology adopted, the students solved two problems based on studies previously consolidated in the literature. The first, a regression problem, consisted of estimating real estate prices from a database with descriptive attributes. The second, a classification problem, involved risk analysis for granting bank credit, using historical customer characteristics. Subsequently, public databases available on the internet were presented, and the students were encouraged to search for real data sets from their companies or workplaces, with the aim of generating insights relevant to their professional contexts.

After selecting the databases, the students were introduced to some of the main supervised Machine Learning techniques, including Decision Tree, Artificial Neural Networks, Support Vector Machine (SVM) and Random Forest. The aim was to give the students a first contact with different algorithms and their practical applications, allowing them to understand the basics of how each approach works, its advantages and limitations.

With this initial knowledge, the groups of students began to investigate what types of insights could be extracted from the selected databases, considering the business objectives or specific interests of their areas of activity. Each group was asked to think about which problem could be solved with the available database and to select the most appropriate algorithm for obtaining meaningful results. Throughout this process, the teacher provided individual guidance, monitoring the progress of each group, helping them to formulate the problem, choose the most appropriate technique and analyse the first results.

3 State of the Art on AI and Machine Learning Education in Engineering

This section provides an overview of the current landscape regarding the teaching of Artificial Intelligence (AI) and Machine Learning (ML) in engineering education, with a particular emphasis on Production Engineering. It introduces a bibliometric review of the main concepts and academic trends related to the integration of AI and ML in engineering curricula, highlighting how these technologies have been addressed in the educational context. Furthermore, it presents key articles that reflect the state of the art in this field, especially those that demonstrate applications in Production Engineering, such as process optimization, decision-making systems, and data-driven project development. The focus is on active learning methodologies and project-based approaches that allow students to engage in practical experiences, enhancing their ability to apply AI and ML tools in real-world, production-oriented scenarios. The next two subsections present the bibliometric analysis and a curated selection of relevant works that illustrate the pedagogical evolution and practical implementation of AI and ML education in the context of Production Engineering.

3.1 Bibliometric Review

This section presents the main results of the bibliometric review, which support the selection of articles analysed in the literature review, aiming to identify the state of the art in the field of study. The analysis enabled the identification of the most influential authors, the institutions with the highest scientific output, and the main international collaboration networks. Additionally, current research trends and recurring themes related to the teaching of Machine Learning in Engineering were mapped. These findings provided objective criteria for selecting the most relevant and up-to-date works that form the theoretical foundation of this study.

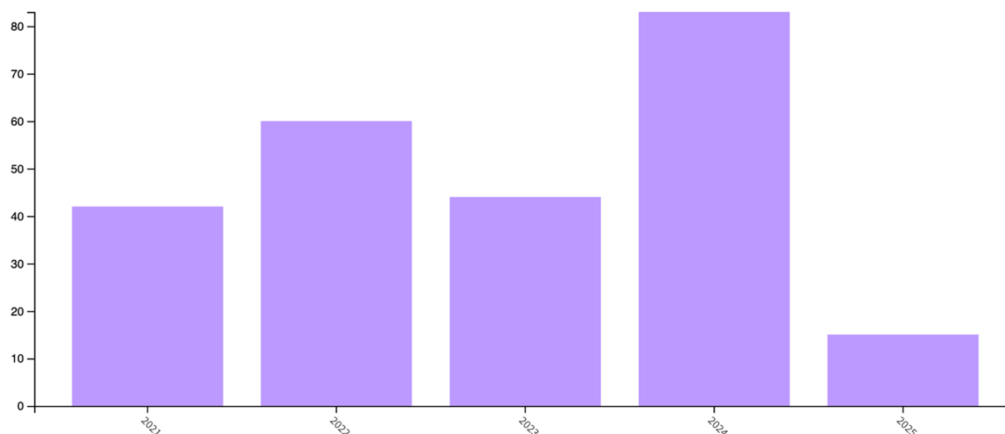


Figure 1. Annual distribution of publications retrieved from the Web of Science database during the analyze period

Figure 1 displays the distribution of publications over the five selected years. It can be observed that, so far, 2025 has a lower number of publications, which is likely because the year is still in its early stages. The year 2024 stands out with the highest number of publications, reaching a total of 83 articles. This data highlights a significant increase in scientific interest in the topic, reflecting its growing relevance within the academic community.

About the scientific output of the authors in the dataset analysed, Kim Phuc Tran, a researcher at the École Nationale Supérieure des Arts et Industries Textiles, stands out as the author with the highest number of publications in the period, totalling four articles. His contributions focus on topics directly related to Production Engineering, with an emphasis on Statistical Process Control (SPC), compositional data analysis, industrial process optimization and the application of statistical and machine learning tools.

Tran's articles include: "Monitoring autocorrelated compositional data vectors using an enhanced residuals Hotelling T^2 control chart", "Analyzing abnormal pattern of Hotelling T^2 control chart for compositional data using artificial neural networks", "Incorporating principal component analysis into Hotelling T^2 control chart for compositional data monitoring" and "Optimal design and evaluation of adaptive EWMA monitoring schemes for Inverse Maxwell distribution" (Imran et al., 2023; Saghir et al., 2023; Zaidi et al., 2023a, 2023b).

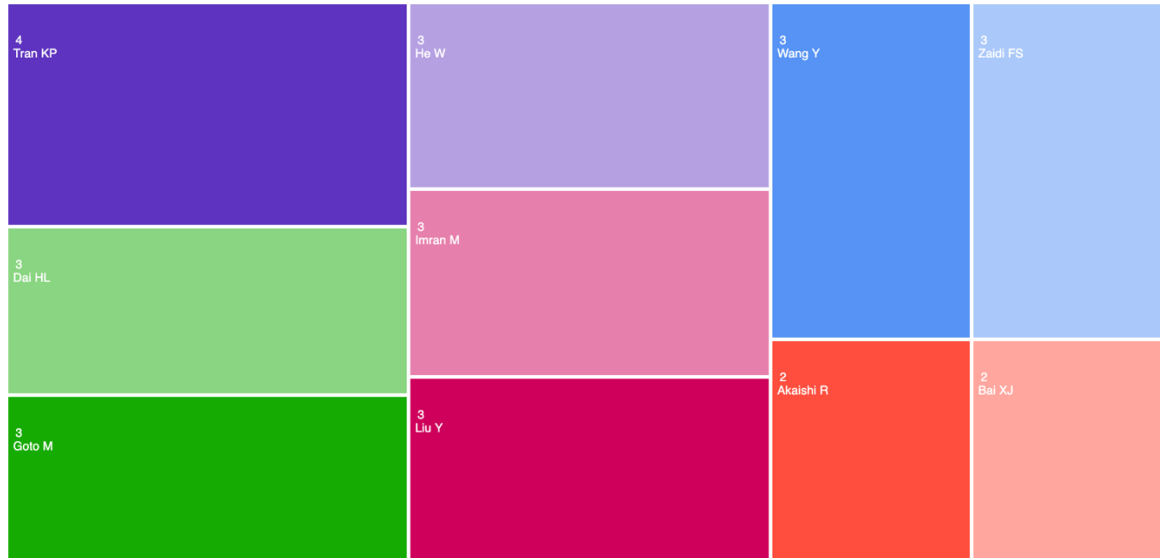


Figure 2. Number of Publications per Author in the Selected Dataset from Web of Science During the Analyzed Period

These contributions reflect a consistent effort to integrate Machine Learning tools into the context of production engineering and its teaching, promoting improvements in the efficiency and accuracy of industrial process monitoring, as well as offering practical applications relevant to the training of engineers in the era of Industry 4.0.

3.2 State of art in the machine learning and IA for engineering

Modran et al. (2021) point out that, according to the World Economic Forum (2020), around 75 million jobs are expected to disappear due to the advance of artificial intelligence. On the other hand, it is estimated that approximately 183 million new jobs will be created, which shows that AI represents not only a challenge, but also a significant job creation opportunity. From this perspective, the authors stress the importance of preparing students for this new reality, emphasizing that it is essential to train them to acquire the skills needed to use artificial intelligence, especially in a context of accelerated digital transformation.

Romero et al. (2021) present an innovative proposal for teaching mathematics in higher education through the EXPLORIA project, which integrates STEAM subjects into a sequential learning process based on active methodologies. The article highlights the need to rethink traditional teaching practices, especially in engineering courses, emphasizing the importance of connecting mathematics to real-life situations, interdisciplinary challenges and applied projects. By integrating mathematical content with subjects such as physics, design and art, the authors observed a significant increase in students' motivation, involvement and positive perception of mathematics. In addition, concrete improvements in academic performance were recorded, most notably a reduction in failure rates and an increase in final averages. The study shows that learning experiences that are more connected to real technologies, such as computational techniques, artificial intelligence and machine learning, contribute to the development of essential skills for training engineers who are prepared for the challenges of the future. Thus, the article reinforces the relevance of integrated, student-

centered methodologies as an effective way of transforming mathematics teaching into a significant element of professional training.

The study proposes the development and implementation of a system made up of hardware and software based on artificial intelligence, aimed at training engineers. The aim is to enable students to understand the fundamentals of machine learning through interaction with modern educational technologies. The main results of the research indicate that the students and engineers involved in the experiment acquired relevant knowledge about machine learning, demonstrating the potential of AI as an effective pedagogical tool in training professionals prepared for the challenges of the future (Modran et al., 2021).

The three articles featuring author Kim Phuc Tran, the most recurrent among the 248 articles analyzed in the bibliometric review, make significant contributions to the field of production engineering, especially in the context of quality and statistical process monitoring. The papers address specific problems related to statistical control charts, with a focus on autocorrelated compositional data, a common type of data in industrial applications (Imran et al., 2023; Zaidi et al., 2023b, 2023a).

In one of these studies, artificial neural networks were used to detect anomalous behavior, i.e. deviations from the normal pattern of the data, even under conditions of autocorrelation. This approach represents an important innovation, combining artificial intelligence and deep learning tools with classical statistical methods, such as Hotelling T^2 control charts and principal component analysis (PCA) (Zaidi et al., 2023b).

The contribution of these articles goes beyond academic research, as they show the potential of neural networks in improving consolidated production engineering tools, such as quality control charts. Such practical application can be especially useful in engineering education, helping to motivate students to learn more about machine learning, artificial intelligence and deep learning, by understanding how these technologies can improve traditional tools that are already part of their technical (Imran et al., 2023; Zaidi et al., 2023b, 2023a)

4 Developed Projects: AI Applications in Engineering Education

The systematic literature review supported the design of the pedagogical approach adopted in this study, highlighting that there is already a significant interest in teaching topics related to Industry 4.0 in engineering education. Although the reviewed methodologies vary in structure and implementation, they share key characteristics: the use of real-world data, the promotion of student autonomy, and the application of machine learning tools to solve relevant problems. These common elements served as a foundation for the development of the classroom activities and guided the instructional choices described in the following sections.

During the course, several projects were developed by different groups of students, each exploring practical applications of Artificial Intelligence (AI) aimed at educational engineering and data analysis. This topic will present some of the most relevant projects, selected based on originality, technical complexity and possibilities for future application.

4.1 Project 1 – Sentimental Analysis in Social Media

The first project focused on sentiment analysis in social media posts, aiming to evaluate the effectiveness of different machine learning algorithms using multimodal inputs (text and image). The students conducted a literature review on multimodal sentiment analysis and explored several datasets from platforms such as Instagram (via InstaLoader), Amazon Reviews, commodity market news, and public repositories like Kaggle and Hugging Face. They faced real-world data collection and preprocessing challenges, especially regarding balancing datasets and cleaning social media comments with informal or ironic language.

To address the problem, the students tested a range of classification algorithms, including Decision Tree, Neural Network, Naive Bayes, and Linear Regression. The most successful results were achieved using a Decision Tree model trained on over 500,000 Amazon reviews and validated on social media comments, particularly from Starbucks campaigns. The students also implemented a DistilBERT-based model from Hugging Face for comparison, which allowed them to understand the practical trade-offs between traditional and deep learning approaches.

Evaluation metrics included accuracy, F1-score, precision, recall, ROC AUC, average precision, and cross-validation. Among all the approaches, the Decision Tree model stood out with a solid overall performance, reaching a mean cross-validation score of 0.872, as well as high interpretability and ease of application. The project offered students hands-on experience with real datasets, algorithm evaluation, model tuning, and performance interpretation — reinforcing core concepts in machine learning and their applicability to engineering problems involving human behaviour data.

4.2 Project 2 – Predicting Oscar Winners Using Machine Learning

In the second project, the students developed a system to predict the winner of the Best Picture category at the Oscars, using data science and machine learning. The database was created with information on the last 24 winners, collected from the Rotten Tomatoes website, a respected source in the film industry. The data was organized in Google Sheets and then transferred to Excel, where it went through a process of cleaning and selecting variables, transforming qualitative data into quantitative data, except for the “winner” variable.

With the base prepared, the students applied different machine learning techniques in Python. The algorithm that performed best was Random Forest, which was used to train and test the model based on information from the films. Among the contenders for the 2024 Oscars were Furiosa, Dune, Planet of the Apes, Madame Teia, Rivals, Imaginary Friends, Civil War, Fall, The Idea of You and Monkey Man - the latter was predicted by the model as the likely winner.

Although the prediction didn't come true, the project provided the students with significant learning in data collection, organization and processing, as well as the application and evaluation of predictive models.

4.3 Project 3 – Construction Decision System

The third project aimed to develop a decision support system based on the collection, processing and analysis of real data from a construction company. Using JavaScript and process automation, the system was applied to the context of project management in the construction industry, with a focus on controlling deadlines and managing the sending and receiving of internal and external documents.

Based on requirements control spreadsheet, code was created to automatically identify which documents were causing the greatest delays, both in internal processes and in dealings with public bodies. The system displayed alerts with the longest analysis times, helping to prioritize the most critical projects and documents.

Analysis of the data revealed that 75.55% of the works had time amendments, with delays in 48.94% of the cases in relation to the planned time - figures compatible with the literature on delays in public works. Thus, the system helped transform operational data into useful knowledge for decision-making and organizational control. Furthermore, improvements were suggested, such as the use of trend analysis techniques and the implementation of automatic notifications to reinforce the system's efficiency.

4.4 Lessons Learned and Project Comparison

Throughout the development of the projects, students learned how to identify and access relevant databases using three different strategies. Based on the chosen datasets and the insights they intended to generate, they

were also able to select appropriate tools, programming languages, and types of machine learning applications to pursue. This autonomy in decision-making was one of the key learning outcomes of the activity. All three projects achieved satisfactory results and sparked students' interest in further exploring Machine Learning, Deep Learning, and Artificial Intelligence—indicating that the main educational objective of the course was successfully met.

5 Conclusion

Current literature highlights the growing need to improve the teaching of emerging technologies such as Machine Learning, Deep Learning, and Artificial Intelligence in engineering education. Several studies already point to this gap and emphasize the urgency of equipping students with skills in these areas, which are rapidly evolving and increasingly demanded in the professional landscape.

The outcomes of this work demonstrate that the classroom methodology was effective. The three student projects clearly showed an understanding of database handling, information processing, and the application of algorithms in decision support systems. As a future direction, it is recommended to maintain and expand elective courses focused on these technologies, reinforcing both the practical and theoretical training of students.

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Agile Methodologies in the Educational Context: A Systematic Literature Review

Danyllo Almeida¹, Mariane Cásseres de Souza², Bibiana Porto da Silva², Rafael Lipinki Paes², Marlon Soliman³, Stefany Brier Costa⁴, Henrique Bertochi⁴

¹ School of Chemistry and Food, Federal University of Rio Grande. Rio Grande, Brazil.

² School of Engineering, Federal University of Rio Grande. Rio Grande, Brazil.

³ Technological Center, Federal University of Santa Maria. Santa Maria, Brazil.

⁴ Computer Science Center, Federal University of Rio Grande. Rio Grande, Brazil.

Email: danyllodan40@gmail.com, marianecasseres@gmail.com, bibiana.ea@gmail.com, rpaes@furg.br, marlon.soliman@ufsm.br, sbcfurg@gmail.com, henriquebg.bg@gmail.com

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Abstract

The application of agile methodologies in the educational context has emerged as an innovative strategy for developing technical, behavioral, and managerial competencies. This study aims to investigate the applicability of agile methodologies in the educational context. Through a systematic literature review in databases such as Scopus and Web of Science analyzed 27 peer-reviewed articles that met the predefined inclusion criteria were analyzed. The results show that agile methodologies promote organization, collaboration, creative problem-solving, and increased student engagement and autonomy. However, educators and institutions identified difficulties such as initial resistance to change, the need for training, and cultural challenges as barriers to effective implementation. Studies show that, when combined with methodologies such as Project-Based Learning (PBL), agile practices can significantly enhance students' motivation, communication, and collaboration skills. In addition, these approaches enable the creation of dynamic and flexible learning environments aligned with the needs of a constantly changing world. Finally, agile methodologies have great potential to transform teaching, offering adaptable structures that meet the demands of learning environments. This study reinforces the relevance of exploring and adapting agile methodologies to the specificities of the educational environment, contributing to the construction of more effective and dynamic pedagogical strategies.

Keywords: Agile methodologies. Scrum. Kanban. Engineering Education. Literature Review.

1 Introduction

The demands of the modern world drive a continuous flow of innovation in society. In the academic context, universities have intensified their efforts to get closer to the business sector. The growing market demand has stimulated the transformation of classrooms, to ensure that students develop not only solid theoretical knowledge in their areas of study but also essential transversal skills fundamental for a complete professional performance aligned with contemporary demands (Castaño Urueña et al., 2024; Ogunrinde, 2022).

The literature shows some problems related to the traditional teaching model, where students are not able to solve problems, work in teams, and communicate. Assessment in the traditional teaching model consists of a process carried out at the end of the course, where the competence achieved is the ability to pass the final exam (Hansen & Luxhøj, 1995; Souza et al., 2019).

The agile approach, which originated in the context of Information Technology (IT), is now prominent in the educational context, where institutions teach agile methodologies and real-world scenarios to prepare and develop future professionals (Souza et al., 2022). Process agility and continuous learning have become important requirements for employees and organizations. Professionals have developed agile methodologies as an alternative to traditional models, based on the premise that every project, regardless of its size, has inherent complexity and is influenced by multiple variables and factors that may affect its development. These

methodologies also provide an alternative approach to conventional teaching methods (Castaño Urueña et al., 2024; López-Alcarria et al., 2019; Sharp & Lang, 2018).

Although the importance of agile methodologies in the professional context is well established, there are still knowledge gaps regarding their application in the academic environment. Given this scenario, this study seeks to answer the following research question: What are the most widely used agile methodologies in educational contexts? The study aims to analyze the applicability of agile methodologies in the traditional context.

Therefore, the study identified and analyzed the main agile methodologies applied in the professional contexts of engineering, management, business, and IT, and evaluated their adaptation to the academic environment. This study used a Systematic Literature Review (SLR) method, which maximizes the potential of a search by finding the highest possible number of results in a more organized way (Alfonso et al. 2021; Moher et al. 2009).

2 Reference Theoretical

2.1 Agile Methodologies

Agile methodologies originated from the Agile Manifesto, created by information technology (IT) professionals in 2001. Although initially focused on software development, they were soon applied to other fields, such as product development and project management (Cooper & Sommer, 2016; Könnölä et al., 2016; López-Alcarria et al., 2019; Mota et al., 2022; Xu & Koivumäki, 2019).

Several methods based on agile principles have since emerged, including Scrum, Kanban, eXtreme Programming (XP), Crystal, Dynamic Systems Development Method (DSDM), and Feature Driven Development (FDD). Among these, Scrum and Kanban are the most widely used. Their adoption allows organizations to respond quickly to changes, reduce development time and costs, increase team motivation, and promote collaboration and knowledge sharing (Cooper & Sommer, 2016; Könnölä et al., 2016; López-Alcarria et al., 2019; Mota et al., 2022; Xu & Koivumäki, 2019).

Scrum is one of the most popular agile methodologies. It organizes projects into time-limited cycles called sprints, typically lasting two to four weeks, which are repeated until project completion. Scrum teams include: (i) developers, responsible for the tasks; (ii) a Product Owner, who defines project requirements and manages backlogs; and (iii) a Scrum Master, who facilitates the process and removes obstacles (Sutherland, 2001; Schwaber & Sutherland, 2017; López-Alcarria et al., 2019).

Kanban, meaning "visual card" in Japanese, is a flexible approach that uses visual boards divided into columns such as "To Do", "In Progress", and "Done". It allows teams to track progress and manage tasks with greater visibility. Unlike Scrum, Kanban does not use fixed work cycles but limits the number of simultaneous tasks, helping prevent overload and identify bottlenecks. Kanban boards can be physical or digital, and tools like Trello are commonly used for remote collaboration (López-Alcarria et al., 2019).

2.2 Agile Methodologies in the Educational Context

Education involves various types of projects that require effective management to meet objectives. Given the success of agile methodologies in the private and public sectors, their integration into education has been gaining traction, particularly when compared to traditional teaching methods (López-Alcarria et al., 2019; Nuottila et al., 2016).

Agile methods are commonly introduced in education through Project-Based Learning (PBL), which fosters a student-centered approach and promotes interdisciplinary skills like teamwork and planning, increasing student motivation and engagement (Zapater et al., 2013).

A study by Zapater et al. (2013) applied Scrum in conjunction with PBL in two engineering courses, challenging students to develop a complex team project in which they applied the methodology to solve real-world problems. The research revealed that students who participated in this approach showed greater motivation, satisfaction, and engagement than students in courses using traditional methods. This dynamic learning model encourages cooperation and self-management, bringing students closer to practical situations similar to those experienced in the job market.

The study by Valentin et al. (2015) corroborates Zapater et al. (2013); they sought to develop several soft skills in an integrated manner, while minimizing disruption to students' academic routines. The team adopted the Scrum methodology and achieved significant results. The organization stood out among the main advances reported, as students realized that the precise definition of guidelines, roles, and structured events contributed to maintaining focus and motivation in research projects. In addition, communication also showed significant improvements, as the proposed structure facilitated interaction between students and researchers, making it more efficient and productive (López-Alcarria et al., 2019).

3 Methodology

This study employed a Systematic Literature Review (SLR) to achieve its research objectives. Data was collected from the Scopus and Web of Science databases, following a structured process:

- 1) Search for the terms (" agile methodologies *" OR " agile project management*" OR " agile frameworks*") in the databases.
- 2) Selection of articles published in journals.
- 3) Results were limited to fields of interest (Computer Science, Engineering and Business, Management and Accounting).
- 4) Results were limited to document types (Article and Review).
- 5) Results were limited to language (English).
- 6) Articles with the keyword agile methodologies in the abstract were selected.

The articles were analyzed according to the steps in Figure 1, presenting the Prisma Flowchart related to the database search. This flowchart follows the guidelines of the PRISMA model (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), proposed by Moher et al. (2009), which guides the conduct and reporting of systematic reviews. It describes the study selection process, including the identification, screening, eligibility, and inclusion phases, and ensures greater transparency and reproducibility of the selected articles.

It is important to acknowledge a potential limitation regarding the choice of search terms. Although the expressions used ("agile methodologies*", "agile project management*", and "agile frameworks*") may not capture the full breadth of studies that intersect agile practices and educational contexts, they are believed to broadly encompass the most relevant contributions to the theme. This approach aimed to balance specificity and inclusivity, ensuring a representative sample of the literature available in the selected databases.

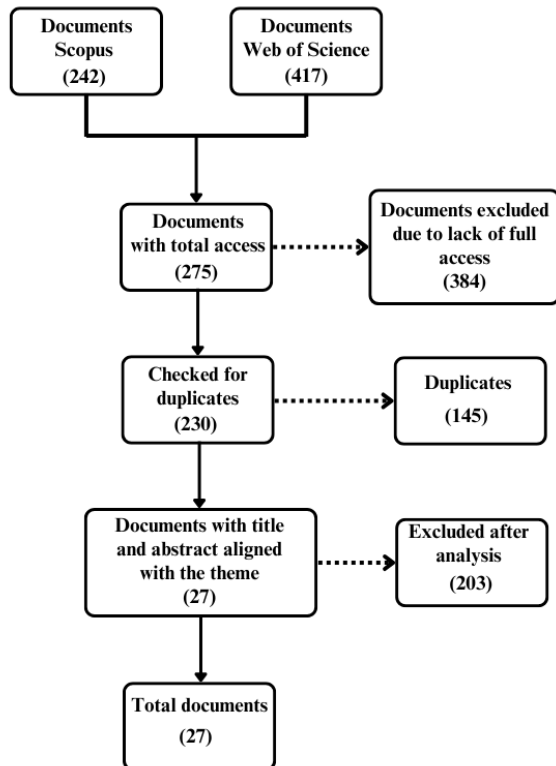


Figure 1. PRISMA method

4 Results and Discussion

The analysis of the twenty-seven (27) selected articles revealed that most applications of agile methodologies are concentrated in Information Technology (IT), representing 44% of the studies. This is followed by management and business contexts with 33% and engineering with only 11%.

The lower representation in areas such as education, management, and engineering suggests that these methodologies still face challenges adapting to contexts with more rigid structures, complex processes, or less dynamic organizational cultures. Therefore, it is necessary to analyze how IT learning can be transferred to other contexts, considering the specificities of each context (Bakar & Dorasamy, 2023; Soares et al., 2022; López-Alcarria et al., 2019).

4.1 Benefits and Challenges of Agile Methodologies in the Educational Context

López-Alcarria et al. (2019) highlighted that there is empirical evidence in the literature on the application of agile methodologies in education. This evidence shows how agile methodologies have become a topic of growing interest in several fields, including the educational context, with an exponential number of experiments and experiences reported in recent years.

The main benefits of adopting agile methodologies in education are the acquisition of skills such as critical thinking, uncertainty management, effective communication, respect for opinions, collaborative work, dialogue, responsibility, and systemic thinking. These skills are essential for the personal and professional development of students and prepare them to face the challenges of the job market (López-Alcarria et al., 2019).

In support of these findings, Elgueta (2016) conducted a study in higher education in software engineering using agile methodologies such as Scrum and Kanban in the context of service learning. The study aimed to

train students to develop software using agile methods. The results indicated that students developed relevant skills, such as the analytical ability to solve complex problems and to work effectively in teams.

These studies demonstrate that agile methodologies, particularly Scrum and Kanban, can be effectively applied in higher education. These practices foster technical skills and significantly enhance behavioral competencies, making them valuable tools for teaching and learning (Elgueta, 2016; López-Alcarria et al., 2019).

Due to several barriers, the implementation of agile methodologies in industries outside of the traditional information technology (IT) domain remains a significant challenge. One of the main barriers is related to investment in training, which is essential for teams to understand the theoretical foundations of agile methodologies and their practical application in different contexts. Many organizations are reluctant to allocate financial resources and time to train their teams, especially in sectors where the concept of agility is not yet widely recognized as a strategic differentiator.

Table 1 presents the benefits and challenges of applying these methodologies

Table 1. Benefits and Challenges of applying Agile Methodologies

Authors	Context	Methodologies Agile	Main Benefits	Main Challenges
Álvarez & Roibás-Millán, 2021 Soares et al., 2022 Soueid & Cora Martins, 2021	Engineering	SCRUM, FDD, ASD, XP, DSDM, CRISTAL	Reduction in development time Resource optimization.	Project complexity Resistance to change
Larson & Chang, 2016 Nerur et al., 2005 Özkan & Mishra, 2019 Riaz et al., 2018 Ríos & Pedreira-Souto, 2019	Information Technology (IT)	Extreme Programming (XP), SCRUM, KANBAN, Scrum for safety	Flexibility and Adaptability Collaboration and Communication Speed and Efficiency, Product Quality	Complexity of tools Team competence Resistance to change
Castaño Urueña et al., 2024 Lopez-Alcarria et al., 2019 Zapater et al., 2013	Education	SCRUM, KANBAN	Greater student engagement Continuous feedback Improved collaboration Adaptability, creativity	Planning overload Resistance to change Time Management
Abukhamis & Abdelhadi, 2022 Ahsan & Ho, 2024 Aránega et al., 2023 Bakar & Dorasamy, 2023 Lishner & Shtub, 2023 Mota et al., 2022 Nyman & Öörni, 2023 Stormi et al., 2019 Suarez-Gomez & Hoyos - Vallejo, 2023	Management and Business	SCRUM, LEAN, BUSINESS MODEL CANVAS, DESIGN THINKING, LEAN KANBAN	Acceleration in Development Improved resource utilization Increase in productivity	Adapting the tools Team Engagement, Risk Management

According to Table 1, in education, approaches such as Kanban and Scrum combined with Project-Based Learning (PBL) have demonstrated the potential to transform pedagogical processes, promoting greater student engagement, improved collaboration, and continuous feedback. However, implementing these methodologies faces difficulties related to planning, which is often overloaded, and time management, especially for educators unfamiliar with agile practices (López-Alcarria et al., 2019; Zapater et al., 2013).

A study by Barbosa et al. (2019) corroborates these findings. The study involved a project to introduce Scrum in the context of PBL with university students. Feedback from the students revealed the benefits of the application, including improved understanding of task division, organization, and teamwork.

Adapting agile methodologies in the educational environment can bring several benefits, such as greater flexibility in learning, improved collaboration between students and teachers, and more dynamic teaching that

adapts to individual needs. These methodologies, widely used in the business sector to optimize processes and increase efficiency, can promote more interactive teaching, stimulate student autonomy, and facilitate curricular adaptation according to the challenges and changes of the modern world (López-Alcarria et al., 2019; Zapater et al., 2013).

Table 2 presents the adaptations of agile methodologies for application in educational contexts.

Table 2. Adaptation of agile methodologies to the educational context

Authors	Methodology Agile	Main Focus	Application General	Adaptation for Education
López-Alcarria et al., 2019 Schwaber & Sutherland, 2017 Sutherland, 2001	Scrum	Organization and collaboration	Iterative project management with sprints	Time management and academic tasks
Lopez-Alcarria et al., 2019	Kanban	Flow transparency continuum	Visual workflow management	Using Kanban boards for learning
Baltador et al., 2024 Mayer & Schwemmler, 2024	Design Thinking	Creativity	Problem-solving with a user-centered approach	Creating solutions for teaching

Table 2 shows that while each methodology has a specific focus, all can be adapted to make education more efficient. Scrum facilitates the organization of academic tasks by structuring activities into well-defined phases, providing greater predictability and control over student progress. Kanban improves visual management by allowing both students and teachers to monitor the progress of activities in real time, facilitating the identification of difficulties and agile decision-making to adjust the process. Design thinking promotes creativity in the search for innovative solutions and encourages critical thinking and experimentation, essential elements for more active and engaging teaching (Baltador et al., 2024; López-Alcarria et al., 2019).

Thus, the selection and combination of these methodologies can improve the educational experience and autonomy of students. Integrating these approaches enables a more flexible, collaborative, and efficient learning environment in which students assimilate content and develop fundamental skills in problem-solving, work organization, and adaptation to different educational contexts. Thus, the implementation of these methodologies in the educational environment can lead to a result in more dynamic, motivating teaching aligned with learning needs (Baltador et al., 2024; López-Alcarria et al., 2019; Zapater et al., 2013).

5 Conclusion

This study presented agile methodologies in different application contexts, identifying Scrum and Kanban as the primary methodologies used in academic settings. The applicability of these approaches in educational environments demonstrates benefits such as increased student engagement, the development of behavioral skills, and flexible adaptation to students' needs.

However, the implementation of these methodologies still faces relevant challenges, such as the need for teacher training, resistance to change, and the need for adjustments to traditional pedagogical models. To overcome these barriers, it is essential for educational institutions to invest in continuous training programs, promote collaborative environments for methodological experimentation, and encourage the gradual adoption of these practices through pilot projects supported by systematic evaluations.

Furthermore, a gap in the literature can be observed regarding the direct comparison between agile and traditional teaching methods, as well as the assessment of their impacts across different educational levels and

areas of knowledge. There is also limited discussion about their practical application in institutions with rigid structures or low technological maturity. Future studies could explore these gaps by investigating, for example, the effectiveness of using Scrum and Kanban in primary or technical education, or in humanities courses, and by evaluating the long-term effects on learning and skill development.

Additionally, as a future perspective, it is important to compare the use of agile methodologies in education with their application in organizational environments. This comparison may reveal more realistic adaptation opportunities, considering that educational settings have structural and cultural particularities, such as individualized evaluation systems and institutional resistance to curricular changes. Studies combining active methodologies with traditional approaches may also contribute to the development of more effective hybrid models.

It is therefore concluded that adapting agile methodologies to the educational reality is not only feasible but necessary to promote training that is more aligned with contemporary demands. The integration of these practices can make education more dynamic, interactive, and student-centered, contributing to the creation of more effective and engaging learning environments.

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Enhancing transversal competencies through PBL: insights from peer and self-assessment

Lílian Barros Pereira Campos^{1,2}, Roger Junio Campos², Janaina Antonino Pinto^{1,3}, Tatiana Gesteira de Almeida Ferraz⁴, Camila de Sousa Pereira⁴

¹ Grupo MAES – Grupo de Pesquisa em Metodologias Ativas do Ensino Superior, Federal University of Itajubá – Itabira Campus, Itabira, Minas Gerais, Brazil

² Federal University of Itajubá – Itabira Campus, Itabira, Minas Gerais, Brazil

³ LALT – Laboratório de Aprendizagem em Logística e Transporte, Universidade Estadual de Campinas, Campinas, Brazil

⁴ Senai/CIMATEC, Salvador, Brazil

Email: liliancampos@unifei.edu.br, rogercampos@unifei.edu.br, janainaantonino@unicamp.br, tatianaa@fieb.org.br, camila.pereira@fieb.org.br

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Abstract

The economic and social demands of the modern world present significant challenges in engineering education, requiring universities to prepare students for professional life. Therefore, it is essential to improve the teaching process to not only address the specific competencies of each engineering field but also develop transversal competencies. These transversal competencies should be integrated into the planning of teaching dynamics and learning assessment. This paper presents an experience with project-based learning (PBL) and transversal competence assessment involving 46 engineering students in an undergraduate Instrumentation course at the Federal University of Itajubá (Unifei) - Theodomiro Santiago campus in Itabira. The students worked in 12 teams to develop solutions to industrial or societal problems. Following the PBL experience, they conducted self and peer assessments of the transversal competencies demonstrated throughout the project. The Soft Skills Assessment System for Engineering Students (SACTEE) was used to assess both types of evaluations, tracking the development of competencies. The findings revealed that students struggled most with conflict mediation, learning from mistakes, willingness to assist colleagues, and fostering collaboration. In contrast, ethics and professionalism, as well as respect for differences, were the highest-rated competencies. These results suggest that such competencies can be better nurtured through intentional learning experiences designed by educators and institutions. This study emphasizes the value of collaborative activities, as they allow students to assess their peers and reflect on their development and contributions to others' growth, thus promoting self-management and leadership skills. The study is part of the "Development of Transversal Competencies (TC)" project, registered on the Brazil Platform (61376922.7.0000.5094).

Keywords: transversal competencies; Engineering Education; self-assessment; peer-assessment

1 Introduction

The new economic and social demands of the modern world present significant and real challenges in engineering education. Engineers face significant challenges when asked to create new technologies and innovations. Talks et al. (2014) argue that universities must take on the responsibility of training professionals who are ready to enter the workforce and be able to progress there. Therefore, engineering schools are confronted with the challenge of teaching specific skills (Ohland et al., 2004) as well as transversal competencies (TC) (Torres et al., 1997). Mitchell, Skinner, and White (2010) understand that TCs can be seen as interpersonal qualities, which in the literature are sometimes referred to as soft skills.

In Brazil, The National Curriculum Guidelines, especially in Engineering, have pointed to the need for higher education institutions to assist students in their specific self-development according to their area of expertise, as well as in their human self-development, regarding generic competencies such as communication, innovation, creativity, among others. In this context, the project titled "Development of Transversal Competencies in Engineering" was created, registered on the Plataforma Brasil with the Ethical Appreciation Presentation Certificate number 61376922.7.0000.5094. These transversal competencies should be integrated

into the planning of teaching dynamics and learning assessment using active learning such as PBL (Problem Based Learning). The PBL is a form of situational learning based on the constructivist findings where the student gains a profound comprehension when he or she gets involved in their knowledge development (Krajcik & Blumenfeld, 2006). This approach has been gaining ground especially in applied science universities due to the student's necessity to develop several learning competencies for the professional environment. It is a technique that provides multifaceted learning experiences as opposed to the traditional teaching method (Lettenmeier, Autio, & Jänis, 2014)

This paper presents an experience with project-based learning (PBL) and transversal competence assessment involving 46 engineering students in an undergraduate Instrumentation course at the Federal University of Itajubá (Unifei) - Theodomiro Santiago campus in Itabira. The students worked in 12 teams to develop solutions to industrial or societal problems. Following the PBL experience, they conducted self and peer assessments of the transversal competencies demonstrated throughout the project. The Soft Skills Assessment System for Engineering Students (SACTEE) was used to assess both types of evaluations, tracking the development of competencies.

2 Transversal Competencies in Engineering Education

In the literature, it can be found a list of several transversal competencies engineers must have, such as communication, creativity, innovation, adaptability, organisation, problem-solving, resilience, proactivity, teamwork among others (Souza & Campos, 2019). In this context, engineering students must be supported, not only in the development of their technical competencies, but also in the improvement of their soft skills.

García-Alvarez et al. (2022) showed a systematic review of the transversal competencies for employability in university graduates from an employer's perspective. They concluded that higher education institutions should adopt pedagogies for employability to strengthen the connection between academic learning and the socio-professional context, thereby facilitating a smoother and more effective transition of graduates into the workforce. Belchior-Rocha et al. (2022) identified the perception of recent graduates as to the importance of the transversal skills that they acquired and developed at university and the ways in which they are now applied in the work environment.

The transversal competencies are increasingly used by engineering professionals who are looking for professionals with skills beyond technical expertise, capable of working in multidisciplinary environments and with a high capacity for adaptation. Traditional training, focused on the transmission of content, has been insufficient for the development of these skills, making it urgent to adopt pedagogical practices that favor more integrated and collaborative experiences.

3 PBL: Project Based Learning in Engineering Courses

The active Project Based Learning (PBL) methodology is a student-centered pedagogical approach in which knowledge is constructed through the investigation and resolution of complex problems, usually linked to real-world situations. According to Thomas (2000), PBL involves a central project as an organizing structure for the teaching-learning process, promoting student engagement and protagonism. Projects are challenging, multidisciplinary and require the application of diverse knowledge for their completion, creating a more authentic and meaningful learning environment. Lima et al. (2017) showed that active learning engages and challenges students using real-life and imaginary situations where students engage in such higher-order thinking tasks as analysis, synthesis and evaluation.

The application of Project Based Learning (PBL) in engineering has proven essential to align academic training with the demands of the professional market, which requires engineers with integrated technical skills and interpersonal competencies. This methodology allows students to face real engineering problems, promoting the development of skills such as logical reasoning, decision-making, leadership, teamwork and effective communication. According to Hernández-de-Menéndez et al. (2019), PBL provides more active and contextualized learning, allowing students to understand the applicability of theoretical content in practical situations. The use of PBL in engineering courses contributes to the development of students' autonomy and capacity for innovation, making them better prepared to deal with complex challenges in multidisciplinary and technologically advanced environments (Shinde and Kolmos, 2011; Askehave et al., 2015).

In the context of transversal skills – such as communication, empathy, problem-solving, leadership and teamwork – PBL has proven to be particularly effective. The collaborative nature of the projects encourages interaction between students, promoting the development of interpersonal and socio-emotional skills. Furthermore, by working with integrative and relevant themes, PBL favors interdisciplinarity and contextualization of teaching, strengthening the link between theory and practice and preparing students for the challenges of personal, academic and professional life (Lima et al., 2017; Hernández-de-Menéndez et al., 2019).

4 Study Context

Project-Based Learning (PBL) was the chosen pedagogical approach for the implementation of a hands-on, real-world learning experience at the Federal University of Itajubá (UNIFEI), located in Itabira - Minas Gerais, Brazil. This strategy was chosen to promote active learning through the investigation and resolution of real-life problems, fostering the development of essential competencies for students' professional formation. Additionally, the adoption of PBL aimed to make the learning process more dynamic and engaging, bridging the gap between theoretical knowledge and practical application.

The project was conducted within a technical discipline that is part of the sixth-semester curriculum for students enrolled in the Electrical Engineering and Control and Automation Engineering programs. This course comprises approximately 90 hours (64 theoretical and 32 practical), with a significant portion of the practical classes held in the instrumentation laboratory.

The central objective of the project was to solve a real-world problem through the design and assembly of a sensor-based system for signal conditioning. Students were tasked with developing an electrical signal conditioning circuit that outputs signals within the 0 to 5 Volt range—standard in industrial applications—requiring the mandatory use of at least one sensor. The final prototype had to be delivered on a prototyped electronic board, with signal conditioning achieved using operational amplifiers.

Students were organized into groups of five, each led by a designated group leader to simulate a company-like structure with defined roles, responsibilities, and operational rules. Throughout the semester, students engaged in collaborative and practical activities, applying theoretical concepts in a problem-solving context. They conducted research, participated in discussions, and overcame challenges related to circuit design and system integration, enhancing their problem-solving skills, critical thinking, and creativity.

The culmination of the project involved presenting the developed prototype as if launching a commercial product, in front of a review panel composed of professors and industry professionals. The project accounted for 25% of the final course grade, with additional assessment components including written tests (45%), exercises (20%), and group seminars on specific content topics (10%).

Project evaluation considered several criteria: (i) peer collaboration, measured through four peer-assessment rounds during the semester; (ii) functionality of the final prototype; (iii) quality of the final written report; and (iv) effectiveness of the final presentation. The distribution of the 25 credits assigned to the project is shown in Table 1.

Table 1. Distribution of the 25 credits assigned to the project

Aspects assessed in the project	Percentage of project credits
Peer assessment	10%
Functional prototype	40%
Final paper	20%
Presentation	20%
TOTAL	100% $\equiv$ 25 credits

In this course, students developed a variety of innovative projects, including a voltage harmonics meter, anti-sleep glasses, a smart irrigation system for monitoring temperature and humidity (smart ground), an oximeter, an automatic fire detection and extinguishing system, an automated greenhouse with control mechanisms to maintain basic environmental parameters, a decibel meter, an automatic curtain, and a position control system using an ultrasonic sensor.

5 Materials and Method

This research was conducted within the scope of the project titled "Development of Transversal Competencies in Engineering," which aims to identify favorable conditions for the development of transversal competencies (TC) among engineering students. Through a proposal for adopting the Plan-Do-Check-Act cycle applied to the development of TCs, this project has been used to assess the effectiveness of active learning strategies (Campos & Pinto, 2023a), the impact of different feedback modalities in remote teaching (Campos & Pinto, 2023b), and to clarify the TCs expected from engineers in training (Pinto, Campos & Lima Jr, 2024).

Considering the perspective of Prodanov and Freitas (2013), this research is characterized as basic in terms of its results, since the results help researchers understand the phenomenon. In terms of its objective, this research can be considered descriptive, as it will enable the description of how the investigated phenomenon occurs within the scope of the research. The problem approach is quantitative, as data collection on self-assessment and peer assessment of engineering students' TCs was carried out through a survey method.

The data collection instrument was the Transversal Competencies Evaluation Questionnaire (QuACT) in the Self-Assessment and Peer Assessment Scales of the Transversal Competencies Assessment System for Engineering Students (SACTEE), developed by Ferraz (2023). It is a data collection instrument suitable for the present study due to its psychometric quality, content validity, internal consistency, and replicability potential (FERRAZ, 2023).

The QuACT proposes the evaluation of 23 TCs, as described in the theoretical framework. The students were sent an Excel form through which they performed both their self-assessment and the peer assessment of their colleagues. For each TC assessed, students had to fill out a table considering their perception of the abilities demonstrated by themselves and their teammates. Thus, students were asked to select a score from 0 to 5 for their perception of the demonstration of each TC, where 0 = Not observed during the period; 1 = Barely developed; 2 = Slightly developed; 3 = Moderately developed; 4 = Well developed; and 5 = Very well developed.

The data were consolidated in spreadsheets and analyzed based on the frequency of responses at each level (0 to 5) for each question. The next section presents and discusses the results of the self-assessment and peer assessment of the TCs demonstrated by the students.

6 Results and Discussion

Based on the collected data, analyses were conducted using both student self-assessments and peer assessments. The data were aggregated to generate insights and reflections on the group of students who participated in the experience.

Among the 56 students enrolled in the analyzed group, 82% completed the questionnaire. However, only responses from teams with at least three participants were considered valid, as each team consisted of up to five members. This criterion was established to ensure that peer assessments were representative of each team. In total, 46 valid responses were included in the self-assessment analysis, while 172 responses were considered for the peer assessment.

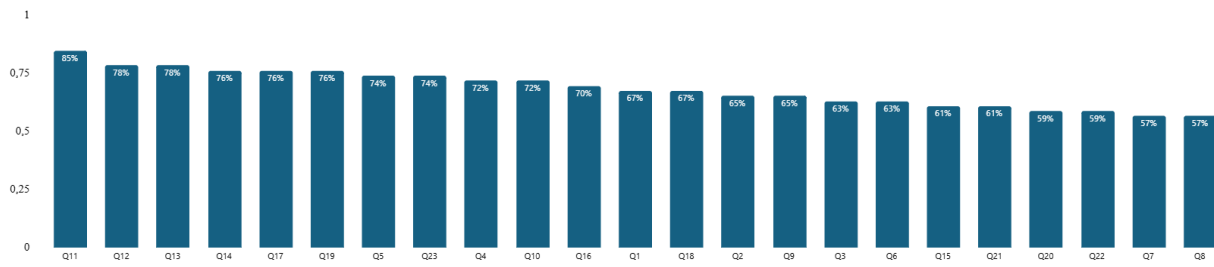
Table 2 displays the frequency of responses by TC across the self-assessment and peer-assessment scales. To enhance visual interpretation, conditional formatting was applied in Excel: cells are shaded in red to indicate lower frequencies and in green to indicate higher frequencies.

Table 2. Frequency of responses by scale level in the self-assessment (n = 46) and peer assessment (n = 172)

#	Central Aspect Assessed	Frequency of Responses - Self-Assessment (%)						Frequency of Responses - Peer-Assessment (%)					
		0	1	2	3	4	5	0	1	2	3	4	5
Q1	Identification of critical points for the work	0%	0%	0%	4%	22%	67%	1%	1%	2%	8%	17%	71%
Q2	Expression of creativity	0%	0%	0%	11%	17%	65%	1%	1%	1%	7%	22%	69%
Q3	Argumentation skills	0%	0%	0%	7%	24%	63%	1%	1%	2%	3%	24%	69%
Q4	Persistence	0%	0%	0%	9%	13%	72%	1%	1%	1%	6%	18%	73%
Q5	Adaptability	2%	0%	0%	2%	15%	74%	1%	1%	1%	2%	21%	74%
Q6	Autonomous learning	0%	0%	2%	4%	24%	63%	1%	1%	1%	4%	20%	73%
Q7	Willingness to help colleagues	0%	0%	0%	7%	30%	57%	3%	0%	2%	8%	22%	66%
Q8	Proactivity	0%	0%	0%	9%	28%	57%	1%	1%	2%	4%	24%	68%
Q9	Attendance	0%	0%	0%	7%	22%	65%	1%	0%	2%	6%	15%	76%
Q10	Meeting deadlines	0%	0%	0%	4%	17%	72%	1%	1%	2%	2%	17%	77%
Q11	Respect for differences	2%	0%	0%	0%	4%	85%	1%	0%	0%	0%	5%	92%
Q12	Collaboration with the group	0%	0%	0%	0%	15%	78%	1%	1%	1%	1%	17%	79%
Q13	Ethics and professionalism	0%	0%	0%	0%	15%	78%	1%	1%	1%	0%	9%	90%
Q14	Collective construction of solutions	0%	0%	0%	2%	15%	76%	3%	0%	1%	5%	16%	75%
Q15	Encouragement of collaboration	2%	0%	2%	9%	20%	61%	3%	1%	1%	8%	21%	66%
Q16	Recognition for contributions	0%	0%	2%	4%	17%	70%	2%	0%	3%	0%	16%	79%
Q17	Written communication	0%	0%	2%	4%	11%	76%	3%	1%	1%	3%	17%	74%
Q18	Assertiveness	0%	0%	0%	9%	17%	67%	2%	1%	2%	6%	15%	74%
Q19	Active listening	0%	0%	0%	2%	15%	76%	2%	0%	1%	2%	16%	80%
Q20	Public oral communication	0%	0%	2%	7%	26%	59%	1%	1%	2%	5%	19%	72%
Q21	Conflict mediation within the group	9%	0%	0%	7%	17%	61%	9%	0%	1%	3%	17%	70%
Q22	Learning based on recognizing one's own mistakes	7%	0%	0%	0%	28%	59%	6%	1%	1%	4%	24%	65%
Q23	Openness to receiving criticism and feedback	0%	0%	0%	0%	20%	74%	1%	1%	0%	3%	21%	74%

In the self-assessment, the competencies (CTs) that received the highest frequency of 5 responses were: "Q11 - Respect for differences," "Q12 - Collaboration with the group," and "Q13 - Ethics and professionalism," with 85%, 78%, and 78%, respectively. In the peer assessment, the items that received the highest frequency of 5 responses were: "Q11 - Respect for differences," "Q13 - Ethics and professionalism," and "Q19 - Active listening," with 92%, 90%, and 80%, respectively. These results indicate the TCs that students perceived as being well or very well developed. For better visualization of the differences in the perception of development for each TC, Figure 1 presents a graph with the percentages of students who, in the self-assessment, answered 5, indicating the frequency with which the TC was very well developed.

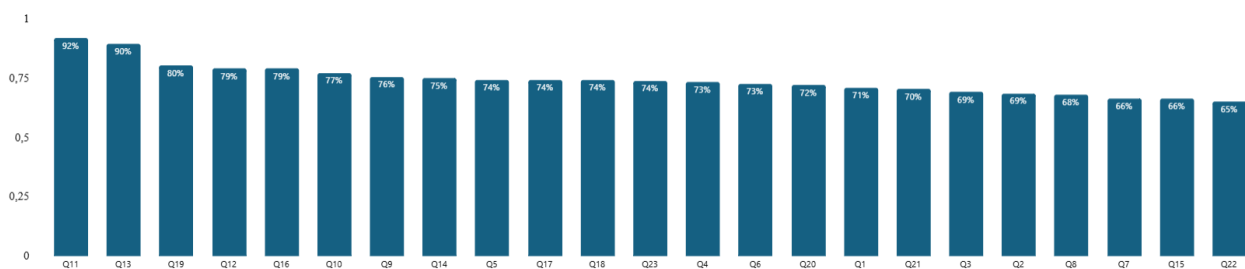
Figure 1: Self-assessment result - percentage of students (n = 46) who answered 5 (very well developed) per TC



Label: Q1 - Identification of critical points for the work; Q2 - Expression of creativity; Q3 - Argumentation skills; Q4 - Persistence; Q5 - Adaptability; Q6 - Autonomous learning; Q7 - Willingness to help colleagues; Q8 - Proactivity; Q9 - Attendance; Q10 - Meeting deadlines; Q11 - Respect for differences; Q12 - Collaboration with the group; Q13 - Ethics and professionalism; Q14 - Collective construction of solutions; Q15 - Encouragement of collaboration; Q16 - Recognition for contributions; Q17 - Written communication; Q18 - Assertiveness; Q19 - Active listening; Q20 - Public oral communication; Q21 - Conflict mediation within the group; Q22 - Learning based on recognizing one's own mistakes; Q23 - Openness to receiving criticism and feedback. Source: Authors, 2025.

On the other hand, the TC's "Q22 - Learning based on recognizing one's own mistakes", "Q7 - Willingness to help colleagues" and "Q8 - Proactivity" with lower or equal percentage than 59%. The frequency of responses 5 per TC is also presented in Figure 2, but now considering the perception of peers.

Figure 2: Peer review result - percentage of students (n = 46) who answered 5 (very well developed) per TC



Label: Q1 - Identification of critical points for the work; Q2 - Expression of creativity; Q3 - Argumentation skills; Q4 - Persistence; Q5 - Adaptability; Q6 - Autonomous learning; Q7 - Willingness to help colleagues; Q8 - Proactivity; Q9 - Attendance; Q10 - Meeting deadlines; Q11 - Respect for differences; Q12 - Collaboration with the group; Q13 - Ethics and professionalism; Q14 - Collective construction of solutions; Q15 - Encouragement of collaboration; Q16 - Recognition for contributions; Q17 - Written communication; Q18 - Assertiveness; Q19 - Active listening; Q20 - Public oral communication; Q21 - Conflict mediation within the group; Q22 - Learning based on recognizing one's own mistakes; Q23 - Openness to receiving criticism and feedback. Source: Authors, 2025.

When comparing the results of self-assessment and peer assessment, it can be seen that transversal competencies Q11 and Q13 had the same perception of being the most developed. In the opposite, the transversal competencies Q7 and Q22 had lower perception in both assessments. These data indicate that, although it is possible to identify common aspects to be worked on by engineering students in a comprehensive way (in more than one class or institution), other aspects may be more particular to certain people or groups, which reinforces the need for systematic evaluation of the transversal competencies.

7 Conclusion

The present paper offers important reflections on the development of transversal competencies (TCs) within the context of engineering education. This study provides references to support the selection of TCs to be developed by students, considering the diversity presented in the existing literature.

The research identified some TCs that students reported finding easier to apply in self-assessment and peer-assessment, such as respect for differences, acting with ethics and professionalism, and collaborating with the group. Collective construction of solutions and active listening also emerged as strengths in the individual and group assessments, respectively. However, one of the TCs students reported having the most difficulty was “learning based on recognizing one’s own mistakes”, in both types of assessments. This highlights the importance of self-awareness in developing the ability to understand that making mistakes can be a valuable part of the learning process. The application of the active methodology PBL also supports this, as it encourages students to reflect on mistakes and learn from them collaboratively. Students also mentioned proactiveness and willingness to help peers as relevant competencies. The PBL technique fosters more collaborative and proactive behaviors within the team, as project success depends on coordinated actions among the group members. These TCs can be better developed through learning experiences planned by both the educational institution and the course instructors.

However, this diagnosis should not be generalized, pointing to the need for a systematic evaluation of students’ TCs in higher education institutions, so that the development strategies for these competencies can be more effectively targeted. In this sense, the importance of collaborative activities is reinforced, as they offer a favorable environment in which students can evaluate their peers and reflect not only on their own self-development but also on their role in contributing to the development of others. This, in turn, fosters self-management and leadership growth. This study presents results from a research project in the field of engineering education. It followed best practices in educational research, including the use of robust data collection instruments developed from validated quality protocols and in accordance with the standards set by the Brazilian National Research Ethics Committee (CONEP).

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From theory to practice: A motion capture project (methodology) as a platform for active and problem-based learning

Jose Amorocho-Rojas¹, Claudia F. Romero-Flores¹, Javier A. De la Tejera¹, Rogelio Bustamante-Bello¹

¹ School of Engineering and Sciences, Tecnológico de Monterrey, Mexico City, Mexico

Email: a01760029@tec.mx, claudia.rf@tec.mx, javierdelatejera@gmail.com, rbustama@tec.mx

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Abstract

A major challenge in engineering education is the effective transition from theoretical knowledge to its application in real-world environments. In this context, participation in consolidated technology projects provides students with the opportunity to apply theoretical concepts in practical scenarios, thereby enhancing their understanding and problem-solving skills. The following article presents the experience of a group of students who participated in a motion capture project based on inertial sensors. The initiative was structured in three phases: validation of the data obtained from the sensors, evaluation of the repeatability of the measurements, and development of a user interface for visualization and analysis of the information. The objective of this project focused on two factors: first, to explore alternatives for motion capture using opto-reflective cameras, and second, to determine the feasibility of performing these tests in the open field. The methodological approach adopted reflects the phases of an engineering development cycle: from conceptualization and system design, through implementation of data acquisition hardware and software, to experimental testing in two scenarios: URe5 collaborative robots and human applications. Finally, this experience demonstrates how the integration of technology projects in engineering can enhance active and problem-based learning strategies. By encouraging multidisciplinary work and direct application of knowledge to real-world situations, it facilitates students' transition from a theoretical approach to an applied, problem-based understanding of engineering.

Keywords: Active Learning; Engineering Education; Problem-Based Learning; Motion Capture.

1 Introduction

The preparation of engineering students for professional practice necessitates a multifaceted approach that extends beyond theoretical knowledge and mathematical foundations. While a robust understanding of these principles is imperative, it is equally crucial to furnish students with opportunities to apply their learning to authentic challenges in the real world. Conventional engineering curricula frequently accord theoretical concepts a higher level of importance than practical applications. This imbalance in curricular emphasis can result in graduate students lacking the necessary skills and experience to effectively navigate the multifaceted challenges inherent in their chosen field (Parkinson et al., 2022).

To address this discrepancy, contemporary engineering education is undergoing a transformation to incorporate projects that consider social, economic, and cultural contexts (Banday et al., 2014), as well as collaborative initiatives between students at various academic levels and partnerships with industry (Tubbs et al., 2024). Despite these advancements, challenges persist in the effective integration of real-world problem-solving into the curriculum and in the development of crucial non-technical skills such as teamwork and communication (Male et al., 2010; Soupeze, 2023).

Active learning methodologies, including problem-based learning (PBL), scenario-based learning (SBL), and inquiry-based learning (IBL), have been identified as promising strategies for addressing these challenges. These approaches facilitate the application of theory, provide access to diverse resources, and foster collaborative learning environments (Marnewick, 2023). PBL, for instance, employs complex, real-world

problems as the primary context for acquiring knowledge and developing critical skills, encouraging inquiry, collaboration, and effective communication (Anchunda & Kaewurai, 2025). SBL and IBL further enhance learning by immersing students in realistic scenarios and promoting exploratory investigation (Nicholus et al., 2023).

A project that focuses on biomechanical applications is one such initiative that aims to address these educational needs. Biomechanics, defined as the study of the mechanics of living organisms (Hamill et al., 2015), is a field that has benefited from the development of tools such as motion capture systems. These systems have enabled the quantification of movement and the provision of objective data for clinical assessments. These systems, which employ technologies ranging from cameras to inertial measurement units (IMUs), present an alternative to subjective evaluations (Gómez Echeverry et al., 2018).

While optoelectronic systems are widely regarded as the gold standard for motion capture, their cost and specialized requirements can impose limitations on accessibility (Cunningham & Brooks, 2022; Romero-Flores et al., 2024). In contrast, IMUs are more portable and affordable, making them suitable for undergraduate projects. However, their accuracy is still under investigation (Taheri et al., 2020). To promote accessible motion capture research, Tecnológico de Monterrey established the SAM research group, which focuses on developing a whole-body motion capture system using IMUs, such as the BNO080 sensor. The goal is to create an accurate, real-time, 3D orientation system using readily available components.

2 Methodology

The methodological design of this project was intentionally structured to exemplify and integrate distinct active learning strategies within engineering education. Each phase of the project corresponded to a specific pedagogical approach: the initial phase was grounded in PBL, the second phase was aligned with SBL, and the final phase incorporated elements of IBL. This alignment was intended to foster the development of both technical and non-technical competencies among participants, including critical thinking, adaptability, and user-centered design.

The SAM research group, established through a collaboration between academic and research entities, is oriented around three principal domains: system design, technological development, and functional performance evaluation. The latter domain constituted the primary focus of the present study.

The methodology employed in this project is thoroughly delineated in the thesis (Amorocho & Perea Calderon, 2022), and it is composed of three sequential phases, each designed to evaluate a different aspect of system performance and student learning. The first phase involved validation in a controlled environment, the second phase extended the evaluation to real-world scenarios, and the third phase addressed the development of a user interface tailored to the needs of end-users.

2.1 Controlled evaluation

In this phase, students had the opportunity to apply theoretical knowledge in a controlled setting, using the UR5e robot to validate the accuracy of the SAM sensors. This facilitated a direct comparison of sensor data with a gold-standard optoelectronic system (VICON), thereby promoting critical thinking and problem-solving as the researchers analyzed discrepancies and refined their measurement techniques.

For this stage, the UR5e robot was used, which consists of a programmable mechanical arm that allows to control the range of movement and the speed SAM sensors were placed on specific robot segments (see Figure 1), as well as the location of markers on the robotic arm to record it with VICON.

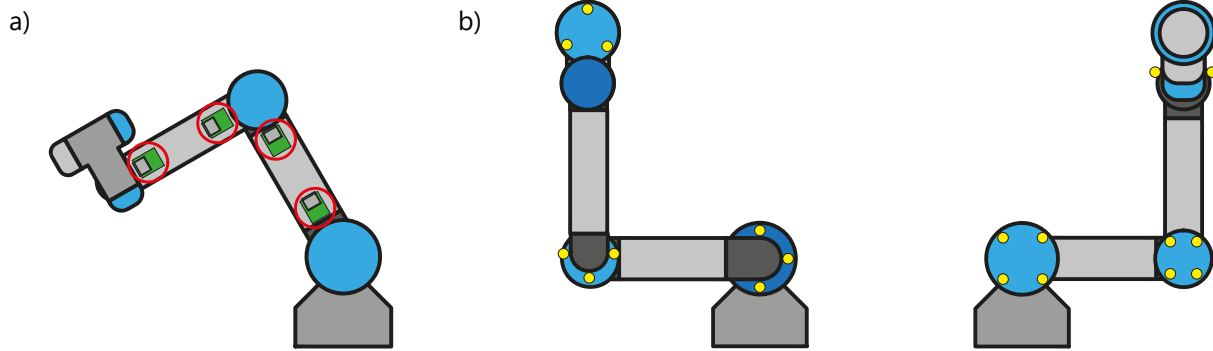


Figure 1. (a) Location of sensors on the robotic arm Ure5. (b) Location of the VICON markers on the robotic arm (represented by the yellow dots)

With this, the UR5e was programmed for three flexion-extension movements (vertical, horizontal and two-link) at five speeds ($5^\circ/s$, $120^\circ/s$, $150^\circ/s$, $180^\circ/s$), as shown in Figure 22, at the beginning of each test, the robot performed a synchronization event, which simulated a football kick.

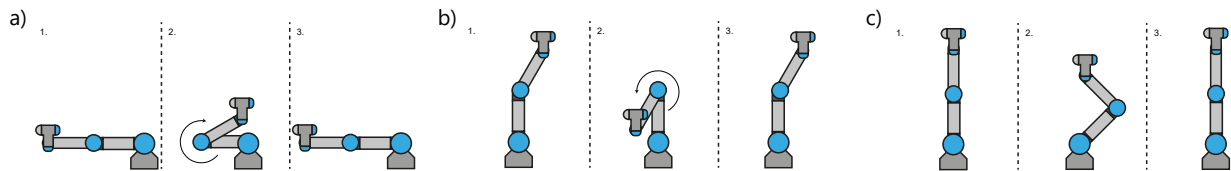


Figure 2. Movement Routine for data validation: (a) Horizontal flexion-extension (b) Vertical flexion-extension (c) Flexion extension 2 links.

All movements were captured simultaneously with the optoelectronic motion capture system Vicon and the SAM sensors. The captured data was pre-processed using NEXUS (software provided by VICON for the acquisition of marker data) and MATLAB, in order to perform a cross-correlation between SAM and VICON data. In this way, the data was compared using the Bland-Altman statistical test, Pearson's correlation and the root mean square error (RMSE) value.

2.2 Evaluation in a real scenario

In this phase, students engaged in Scenario-Based Learning by applying their knowledge to real-world contexts. The subjects were responsible for the installation of the sensors and for serving as test subjects. This required them to adapt to the variability and unpredictability of human movement. This phase placed significant emphasis on teamwork, communication, and the capacity for problem-solving in a less structured environment. During this phase, students had the opportunity to apply theoretical knowledge in a controlled setting, utilizing the UR5e robot to validate the accuracy of the SAM sensors. This facilitated a direct comparison of sensor data with a gold-standard optoelectronic system (VICON), thereby promoting critical thinking and problem-solving as the researchers analyzed discrepancies and refined their measurement techniques.

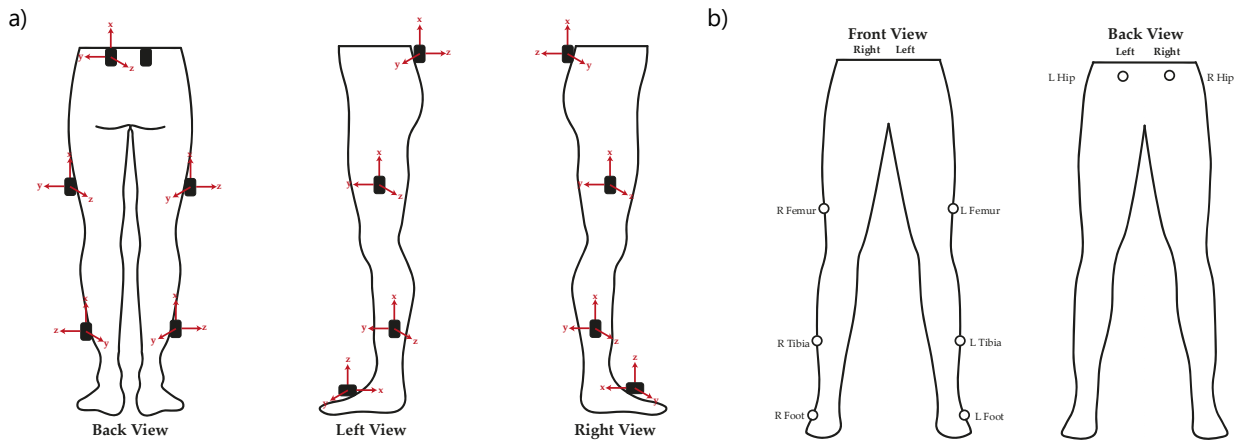


Figure 3. (a) Location of sensors on subjects. (b) Location of the VICON markers on subjects.

For the purposes of the repeatability tests, a set of SAM sensors was installed on the subjects (Figure 3), as well as the location of the VICON markers (see Figure 3), and a two-day test was performed. The participants in the project rotated as researchers to install the sensors and perform the test and rotated as subjects, this test for the information endorsed by a medical service, with informed consent. It consisted of two phases: The first was stretching (Figure 24), in which the participant was asked to maintain a position for a period. The second consisted of four sequences of four repetitions (Figure 4).

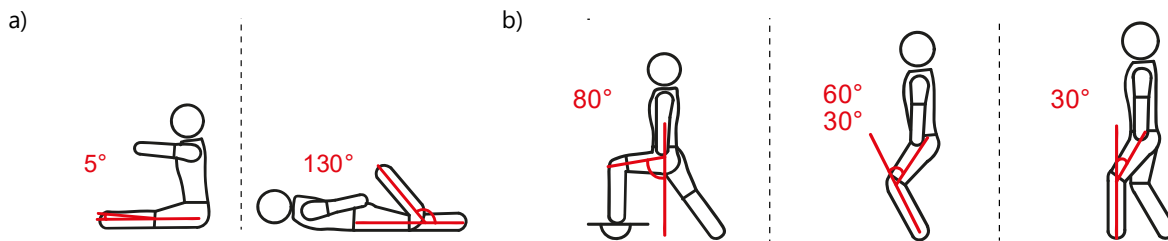


Figure 4. Repeatability test routine.

The collected data underwent processing and transformation into the articular angles of the lower extremity (hip, knee, and ankle). This transformation enabled the determination of flexion-extension, abduction-adduction, and rotation in each of the joints. The difference in measurements for each segment between days and researchers on the same subject was evaluated using the root mean square error (RMSE) value, the Bland-Altman method, and Pearson's correlation.

2.3 User interface approach

In this phase, students engaged in Inquiry-Based Learning by identifying the needs of end-users (healthcare professionals) and designing a user interface that would facilitate the practical application of the motion capture system. This required them to gather feedback, pose questions about usability, and iteratively improve their design based on real-world requirements.

When designing the interface, data that might be of interest to healthcare professionals. Is considered It was important to consider the different stages of data collection, such as patient information, sensor position, and factors associated with patient diagnoses.

3 Results and discussion

In order to comprehend the outcomes of the motion capture project, it is necessary to consider the learning gains, technical results, and challenges encountered by students as they progressed through each project

phase. Rather than reiterating the methodology, this section highlights the key findings and educational impacts associated with each stage.

3.1 Controlled evaluation

The initial phase, conducted in a controlled environment, yielded strong technical validation of the SAM sensor system. Statistical analysis demonstrated a high degree of agreement between the SAM sensors and the VICON reference system, with Pearson correlation coefficients of 0.99 and root mean square errors (RMSE) of 3.41° (lateral) and 3.95° (frontal). These results confirm the feasibility of using low-cost inertial sensors for motion capture in educational and research contexts.

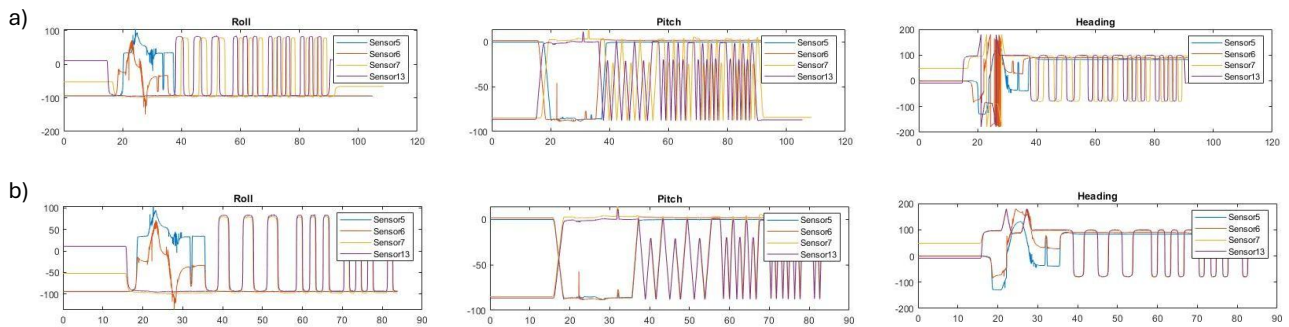


Figure 5. Example of SAM sensor data from phase 1, (a) unsynchronized data b) synchronized data.

Importantly, this phase also fostered significant learning outcomes. Students engaged in the design and execution of a validation protocol, requiring them to apply theoretical knowledge to practical challenges. The process of calibrating sensors, synchronizing data, and interpreting statistical results promoted critical thinking and iterative problem-solving. These experiences are essential for bridging the gap between theoretical instruction and engineering practice.

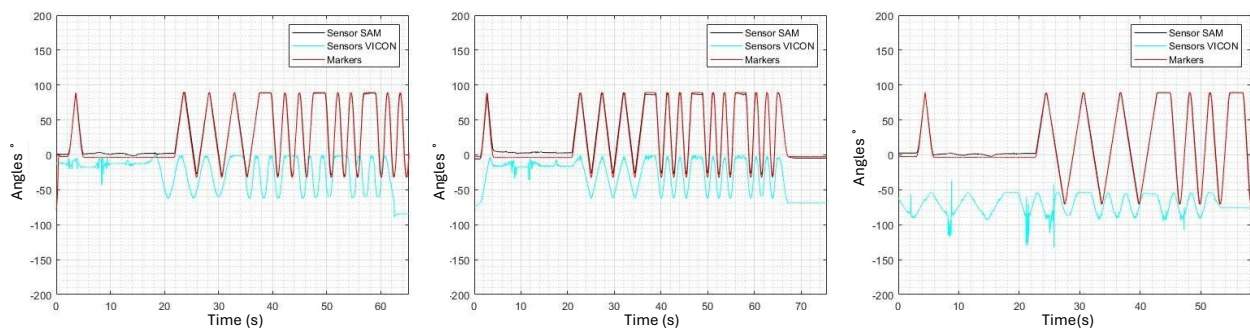


Figure 6. Example of angle determination.

Table 3. SAM vs VICON comparison.

		Lateral	Frontal
RMSE		3.41	3.95
Pearson Correlation		0.99	0.99
Bland-Altman Test	Coefficient of Reproducibility	4.96°	5.30°
	Coefficient of Variation	10%	12.4%

3.2 Evaluation in a real scenario

In the subsequent real-world scenario phase, students applied the SAM system to human subjects, encountering increased variability and complexity. Repeatability tests across lower limb joints revealed moderate correlations and higher RMSE values (e.g., hip flexion-extension RMSE: 9.4°, knee flexion-extension RMSE: 16.6°), reflecting the inherent challenges of human movement analysis and sensor placement consistency. flexion-extension, and rotation with the results summarized in Table 9. Average result of repeatability tests. Table 9. This approach allowed for a comprehensive assessment of the repeatability and accuracy of the SAM system in capturing human motion.

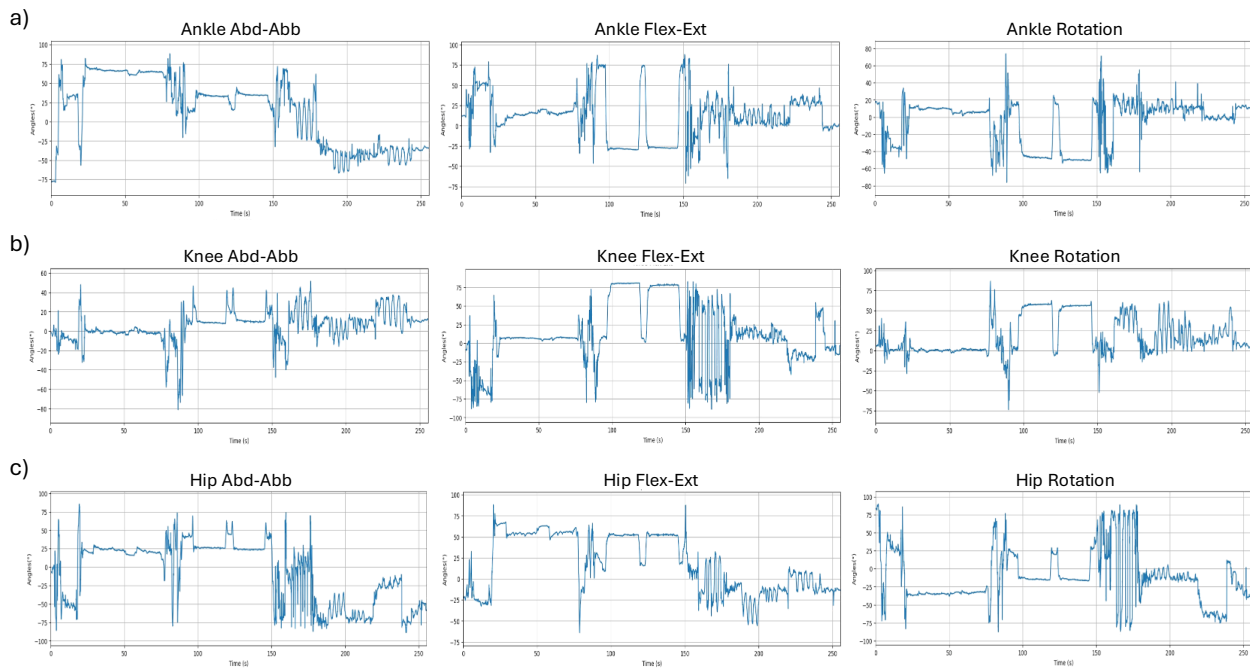


Figure 7. Graphic display example: (a) Ankle angles charts. (b) knee angles charts. (c) Hip angles charts.

Table 4. Average result of repeatability tests.

		r	RMSE	RPC(°)
Hip	Flex ext	0.364	9.417	36.617
	Abd Abb	0.302	14.691	42.944
	Rot	0.296	13.936	50.283
Knee	Flex ext	0.239	16.617	51.072
	Abd Abb	0.351	10.128	60.817
	Rot	0.262	13.067	40.700
Ankle	Flex ext	0.294	16.283	49.278
	Abd Abb	0.227	7.906	23.100
	Rot	0.189	11.106	31.411

This phase was instrumental in the development of non-technical skills. The students alternated between the roles of experimenter and subject, a process which demanded effective teamwork, communication and

adaptability. The necessity to standardize procedures and address unanticipated issues in real time engendered an authentic experience in collaborative problem-solving and project management.

3.3 User interface approach

The user interface, developed in the final phase, was evaluated based on usability and end-user feedback rather than technical implementation details. The interface was designed to facilitate streamlined data entry, sensor mapping, and automated report generation. Feedback from healthcare professionals highlighted the value of customisable data displays and integrated reporting features, emphasising the significance of user-centred design.

The iterative development process necessitated that students gather requirements, test prototypes, and refine the interface based on usability observations. This approach served to reinforce inquiry-based learning and adaptability, two key competencies that are integral to the realm of engineering education.

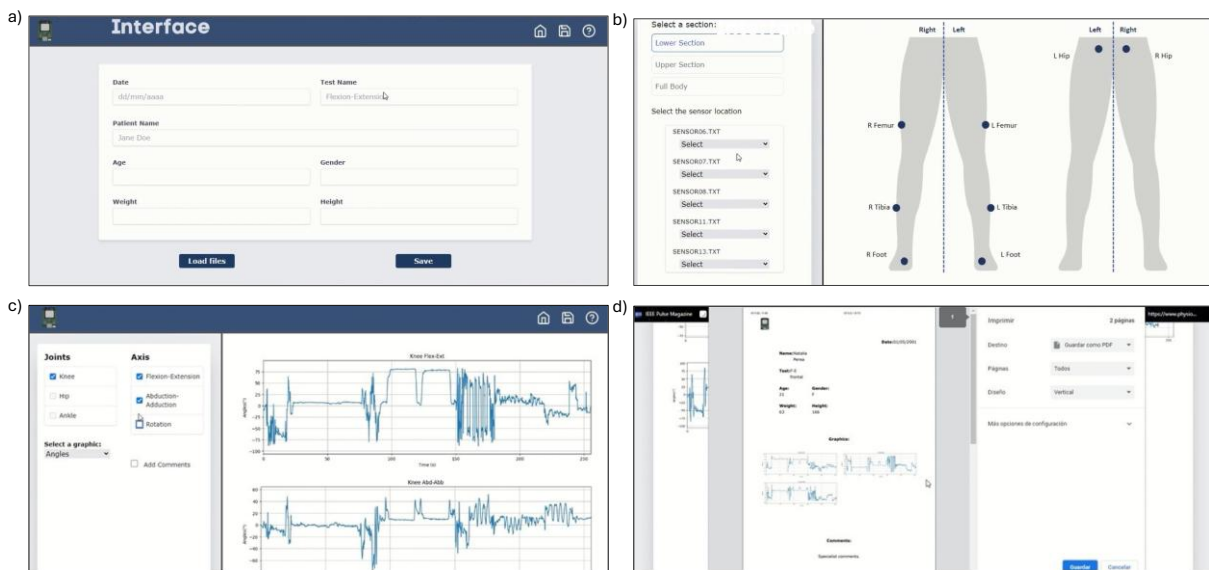


Figure 8. Example of interface implementation (a) Data collection (b) Sensor location (c) Table display (d) PDF document creation.

3.4 Future work

As the project progressed, it became evident that the students exhibited a diverse range of work trajectories, contingent on their specializations and the utilization of tools for various pathologies and domains of practice, including Alzheimer's disease and sports. Future work will focus on expanding the application of the SAM system to a broader range of clinical and research scenarios. For example, the system can be adapted to assess gait abnormalities in patients with neurological conditions such as Parkinson's disease or stroke, monitor rehabilitation progress in orthopedic patients, or evaluate movement patterns in athletes for injury prevention. Additionally, the system's flexibility allows for its use in the early detection of degenerative diseases like Alzheimer's, where subtle changes in movement may serve as early indicators. Its application in the domain of ergonomics evaluation within industrial settings is also noteworthy. By tailoring the system to address the specific needs of different pathologies, the project aims to contribute to more personalized and effective healthcare interventions.

Furthermore, the possibility exists for the establishment of analogous objectives through the utilization of disparate tools, such as cameras in lieu of sensors. This observation underscores the capacity of the application of existing projects to catalyze the conception of novel ones by students (Yu, 2024). This underscores the

importance of integrating experiential learning methodologies into education, fostering critical thinking skills, and broadening students' skill sets to meet the demands and scenarios encountered in the real world.

4 Conclusion

The project yielded concrete evidence of the development of critical thinking, teamwork and communication skills. The students demonstrated critical thinking through the process of troubleshooting and data analysis, teamwork through the coordination of experimental protocols, and communication through the presentation of findings to a variety of audiences. These outcomes align with the objectives of active and problem-based learning, supporting their integration into engineering curricula.

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Development of a Visual Tool for Data Management in Recycling Cooperatives: A User-Centered Approach

Simone Borges Simão Monteiro¹, Yasmim Bezerra Oliveira Altoé¹, Lukas Nunes de Souza¹, Natália Ilha Gattai¹, Pedro Affonso Novais Neves Faria¹, Rodrigo da Rocha e Silva Fregonasse¹, Dianne Magalhães Viana²

¹ Production Engineering, Faculty of Technology, University of Brasília, Brasília, Brazil

² Mechanical Engineering, Faculty of Technology, University of Brasília, Brasília, Brazil

Email : simoneborges@unb.br, 211068190@aluno.unb.br, 170150381@aluno.unb.br, 211026870@aluno.unb.br, 190134003@aluno.unb.br, 211026904@aluno.unb.br, dianne.magav@gmail.com

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Abstract

The Data Management System is essential for increasing operational efficiency by collecting and visualizing data to support informed decision-making by waste pickers. This article evaluates a visual tool for the Data Management System application; a platform designed for recyclable material cooperatives in the Federal District. The project was developed within the Production Project 5 course, using project-based learning (PBL). In this approach, students collaborate to solve real-world problems through research, requirements gathering, prototyping, and validation with stakeholders (in this case, a recycling cooperative), promoting practical and interdisciplinary learning. The app will be developed by software engineering students as part of the Egalitarian project, under the ERASMUS+ program funded by the European Union. The research follows a qualitative, exploratory, and applied approach, focusing on three key aspects. First, it identifies high-level requirements for the web app's functionalities and prioritizes them using the Kano Model. Next, it involves designing the interface screens for the app's modules in Figma, ensuring an intuitive and user-friendly experience. Finally, an interactive and functional dashboard is developed and validated by waste pickers, who will be the app's primary users. The concept was tested at the Recicla Mais Brasil cooperative in the Federal District. The study aims to develop a fully functional system that enables the visualization of key performance indicators, improving operational control and facilitating strategic decision-making for the recycling cooperative.

Keywords: Egalitarian Project, Data Management System, Waste Pickers, Requirements Gathering, Active Learning.

1 Introduction

In the era of technology and with the availability of data present in today's society, information has become a valuable resource for organizations. According to Sarioguz and Miser (2023), the increasing dependence on data is driven by the understanding that when efficiently understood, they can provide valuable insights.

According to Michalski Filho, Resende, and Gaia (2010), recycling cooperatives face significant challenges related to operational efficiency and information management, often due to the lack of integrated data management systems. The absence of suitable tools to collect, organize, and analyse data negatively impacts these institutions' ability to monitor operations and make evidence-based decisions.

Data play a fundamental role in optimizing operational activities to increase the income of collectors (Ferreira, Kintschner & Sugahara, 2022). The managerial difficulties present in this scenario are evidenced by the lack of education among collectors, as more than 80 percent of collectors do not receive formal education beyond primary school, according to Bouvier (2021). Coupled with the lack of instruction, the use of precarious and manual systems fosters distrust and conflict among cooperatives, as noted by Barros and Moura (2022).

The Data Management System (DMS) is a project being developed under the Egalitarian project, which is part of the Erasmus+ Program, funded by the European Union. The Egalitarian project focuses on developing international projects carried out by students under the supervision of professors from different universities, aimed at proposing improvements to the solid waste management system in Brazil, emphasizing recyclable

material collectors in the Federal District. The solutions proposed by the students must align with sustainability and digital technologies, addressing the growing demand for technological tools that aim to increase the competitiveness and sustainability of cooperatives, aligning with environmental and economic needs.

The DMS project emerged in response to a cooperative's demand to visualize accessible data for all collaborators regarding the productivity of collectors, daily production by material type, to facilitate cooperative management and provide greater transparency to members. Considering this context, this article aims to detail the DMS system that was conceived by the students, its requirements and functionalities, prototypes, and dashboards.

2 Theoretical Framework

Recycling cooperatives play a fundamental role in solid waste management, promoting environmental sustainability and social inclusion. However, they face challenges related to operational efficiency and information fragmentation. Ferreira et al. (2022), Barros and Moura (2022) indicate that the adoption of integrated management systems and information technologies can optimize processes, improve decision-making, and increase the competitiveness of these organizations. This theoretical framework explores the importance of these systems, addressing their application in areas such as production, inventory, reverse logistics, and sustainability.

2.1 Integrated Management

Recycling cooperatives play a fundamental role in waste management, promoting environmental sustainability and social inclusion. However, as noted by Michalski Filho, Resende, and Gaia (2010), these organizations face challenges in operational efficiency and information management. The lack of integrated data management systems leads to fragmented processes and ineffective decision-making, affecting competitiveness and sustainability. In this context, the adoption of information and communication technologies (ICTs) emerges as a promising solution to optimize operations and improve the strategic management of recycling cooperatives, according to Barros and Moura (2022). This theoretical framework examines the importance of data management systems in cooperatives, addressing their application in production, inventory, reverse logistics, and sustainability.

Barros and Moura (2022) emphasize that systemic management is essential for the success of waste picker cooperatives. Organizational performance is linked to the management of information technology (IT) and information systems (IS), which requires proper alignment between organizational systems and the IT/IS sector. Henderson and Venkatraman (1993) argued that the economic performance of an organization could be improved by aligning IT strategy with business strategy, as well as aligning infrastructure and organizational processes with IS structures.

2.2 Production and Inventory Management in Recycling Cooperatives

Ferreira et al. (2022) highlight that production and inventory management is one of the main challenges faced by recycling cooperatives, especially due to the lack of tools that allow efficient monitoring of material flow. In this context, the use of technologies based on agile methods, such as Scrum, facilitates the development of customized systems that are adaptable to the specific needs of cooperatives. These solutions enable organizations to have greater control over the materials collected, stored, and reused, minimizing losses and maximizing operational efficiency.

In addition, the system proposed by Ferreira et al. (2022) organizes data into modules, covering everything from sorting control to contract management with clients, integrating all stages of the production process. This

not only improves efficiency but also promotes greater transparency in operations, creating trust among members and stakeholders. By adopting this approach, cooperatives can better meet market demands and position themselves as strategic partners in the sector, strengthening their financial and operational sustainability.

2.3 Requirement Elicitation

Requirements elicitation is a crucial step in system development, as it directly influences the success or failure of a project. According to Sommerville (2011), this activity seeks to identify, document, and validate the needs of stakeholders, ensuring that the final system meets the expectations and proposed objectives. Among the techniques used are interviews, brainstorming, and analyses that help capture relevant information and reduce gaps among those involved. Studies such as those by Wiegers and Beatty (2013) highlight that the application of well-defined techniques improves communication among stakeholders and increases clarity regarding functional and non-functional requirements. Furthermore, the choice of the best technique should consider factors such as the organizational context, project complexity, and available tools. Inadequate requirements elicitation is one of the main causes of rework and project failures in software development, as noted by Glass (2005), reinforcing the need for systematic and collaborative approaches in this phase.

2.4 Usability Principles in Web Interfaces

Usability is one of the fundamental pillars for the success of web interfaces, directly affecting the user experience and the effectiveness of the system. According to Nielsen (1994), a usable interface must be efficient, intuitive, and pleasant, facilitating the user's interaction with the system. Principles such as consistency, immediate feedback, simplicity, and accessibility are widely discussed in the literature and have been applied in various contexts, as reported by Lazar, Feng, and Hochheiser (2017). Research indicates that interfaces that follow good usability practices have higher user retention rates and lower abandonment rates, especially in competitive environments such as e-commerce (Garrett, 2011).

Furthermore, conducting usability tests throughout the development process is essential to identify problems and refine the interface, ensuring a satisfactory experience for different user profiles. These principles become even more relevant as the diversity of devices and usage contexts increases, requiring adaptable and user-centered solutions.

3 Methodology

3.1 Research classification

The article can be classified in terms of purpose as descriptive, as it aims to detail the development and implementation of a system to optimize the management of cooperatives without establishing causal relationships (Gil, 2008). In terms of approach, the research is qualitative, as there is a theoretical review and validation with experts (Creswell, 2010). It is applied research, with the aim of solving a practical and concrete problem, collecting real data and seeking a practical solution to the cooperative's issue, focusing on optimizing management (Lakatos & Marconi, 2017), (Yin, 2015).

3.2 Research structure

The research was structured in 4 stages to report the initial design of the Data Management System.

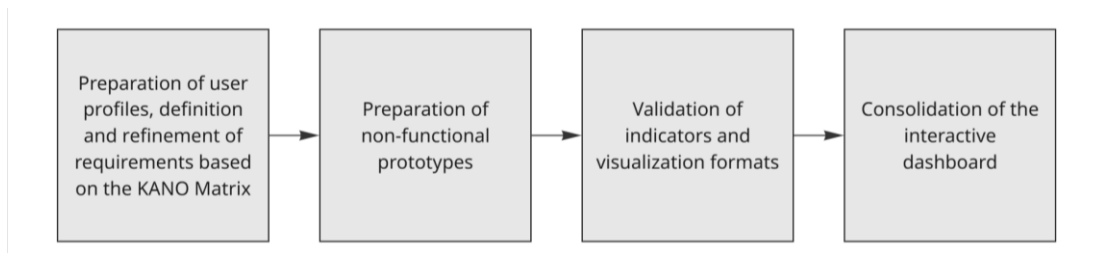


Figure 1. Stages of the research, Developed by the authors (2025)

In the first stage, user profiles were developed, requirements were defined and refined based on the KANO matrix, and the initial data architecture was created following a technical visit to the Recicla Mais Brasil cooperative in the Federal District. In the second stage, the focus was directed towards the development of non-functional prototypes in Figma. In the third stage, another visit to the cooperative was made to validate the indicators and visualization formats. Potential users, cooperative directors, and 4 recyclers were interviewed to validate the information. And finally, in the fourth stage, the interactive dashboard was consolidated, demonstrating the indicators of the cooperative's operations.

4 Results and Discussion

4.1 Cooperative Structure and Organization

To carry out an initial diagnosis of the model cooperative, a technical visit was conducted to understand the organizational structure, the processes carried out, and the data collected in the organization. The organizational structure of the cooperative is divided into two main functions: administrative and operational. The administrative board, made up of waste pickers, plays a strategic and managerial role, being responsible for articulating improvements with other organizations and with the government, selling the sorted material, controlling finances, and supervising operations. The operational part consists of 50 waste pickers who work on the cooperative's production line. This group performs daily activities such as receiving, sorting, and organizing the received material.

The main processes present in the cooperative are sorting, weighing, selling the received material, and paying the members. In the sorting process, the content is separated according to the type and color of the material. In weighing, each waste picker is responsible for weighing the material they handle on that day, while one of the waste pickers from the administrative board manually records the observed weight. Finally, the sale of the material is carried out later by the administration. The data observed in these activities includes: the weight of the material sorted by each waste picker daily, the number of bags of sorted material per day, the selling price of each material, and the payment value for each member. Thus, with the aim of ensuring transparency between the two roles, the DMS system is designed for a Web version, intended for the administrative board, and an app version, proposed for the waste pickers.

4.2 Requirements

The Kano matrix is a tool for classifying and prioritizing product or service requirements based on their impact on customer satisfaction, shown in Figure 2. Developed by Noriaki Kano in the 1980s, it categorizes attributes into five groups: basic, performance, attractive, indifferent, and reverse. According to Sauerwein et al. (1996), this matrix helps development teams identify essential features, those that increase satisfaction proportionally, and those that can pleasantly surprise customers. Its main goal is to guide strategic decisions in product design and development, ensuring value delivery and alignment with target audience expectations.

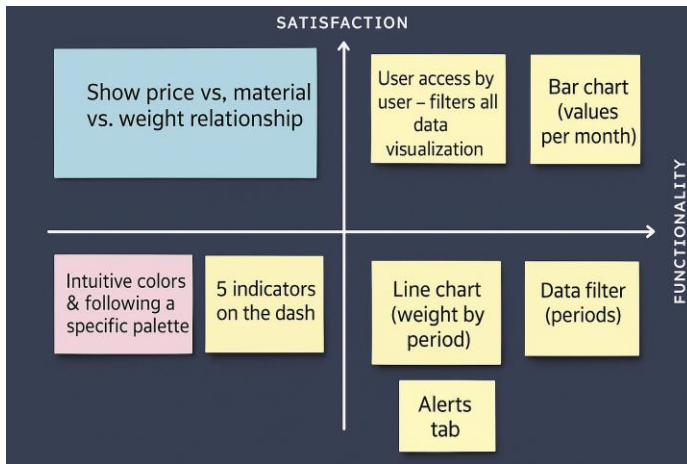


Figure 2. Kano Matrix, Developed by the authors (2024)

Based on the Kano matrix, the requirements were classified and prioritized. Thus, the system requirements gathered, and the functionalities are described in Table 1.

Requirements	System Functionalities
Ability to apply filters for result visualization	Screen filters for: -Date (select time intervals), -Material type, -Waste picker.
An intuitive interface for selecting time periods from a predefined list, without manually entering date ranges	
An intuitive interface for selecting material types from a predefined list, without manually entering names	
An intuitive interface for selecting waste picker names from a predefined list, without manually entering names	Data visualization section containing: -Bar chart showing total production by material type, -Line chart showing total production per day, - Line chart showing total production per waste picker.
Only three response visualizations (outputs) to simplify result analysis	
Charts with thick, visible lines	
Charts with legends and contrasting colors	

Table 1. Requirements and functionalities of the DMS App, Developed by the authors (2024)

Thus, the prioritized functionalities demonstrate the initial characteristics of the system. The implementation of filters facilitates the visualization of individual data, which aids in decision-making. Additionally, the use of bar and line graphs combined with contrasting colors reinforces visual understanding.

4.3 Non-functional prototypes

An app screen prototype is a visual representation that simulates the design and functionality of app interfaces before full development. It can range from a simple paper sketch to an interactive digital mockup, allowing visualization of element placement, navigation flow, and user experience. According to Snyder (2003), prototypes help validate ideas, identify usability issues, and align expectations between stakeholders and the development team. Their purpose is to reduce rework, save resources, and ensure that the final product meets user needs and project goals.

The non-functional prototypes (Figures 3 and 4) were developed using Figma to simulate user interaction and navigation.

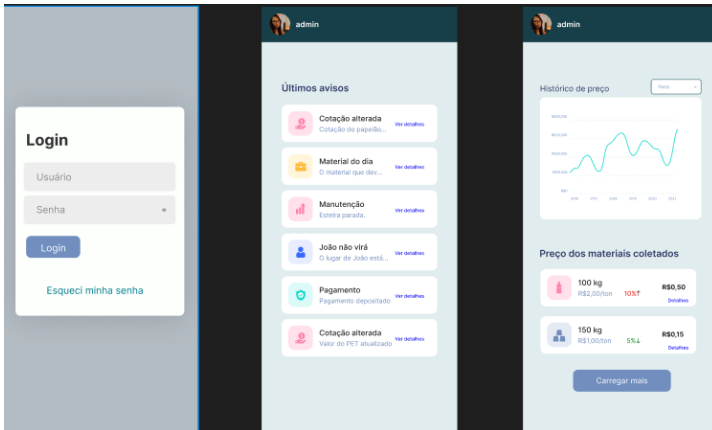


Figure 3. App Screen prototyped, Developed by the authors (2024)

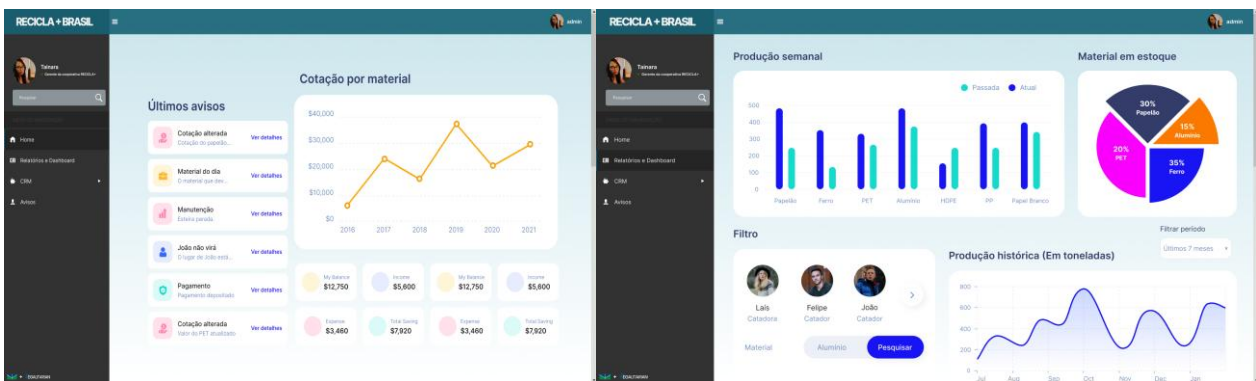


Figure 4. Web Screen prototyped, Developed by the authors (2024)

The app prototype (Figure 3) showcases the mobile interface, highlighting the summary and notification screens to support quick and efficient user interaction. The web prototype (Figure 4) presents the desktop version, emphasizing usability and accessibility, and includes dashboards and analytics to illustrate key data in a clear and visually accessible format. Both were created to simulate the user journey and align with the intended user experience.

4.4 Validation with the cooperative

For the validation of the prototypes and indicators, a technical visit was conducted at the Recicla Mais Brasil cooperative in the Federal District. Three members of the cooperative's board participated, showed enthusiasm for the developed solution, and the desired functionalities were extracted, in addition to those raised. Based on suggestions from the collectors, the need for the development of a functionality to send general notices emerged to ensure efficient communication within the cooperative. The "Send Notice" screen allows users to select recipients, format the text, and schedule notifications, with a send button prominently displayed to facilitate use.

4.5 Dashboard

At the Recicla Mais Brasil cooperative, the scale used to collect the weight of sorted materials is not an automated process, therefore, there are no sensors or hardware implemented, as can be seen in Figure 5.



Figure 5. Digital scale used by the Recicla Mais Brasil Cooperative, Own authorship

The automation project for the scale is being developed by Brazilian students from the Production Engineering and Software Engineering courses, in partnership with Danish students from the Computer Science course. As the process is not yet automated and due to the lack of data recorded in an automated manner, it was necessary to create a spreadsheet with fictitious data, as shown in Figure 6.

Collection Date	Worker	Material Type	Recycled Weight	Sale Value (R\$)	Price per Kg (R\$/Kg)	Hours Worked	Reference Month
10/12/2024	João	Glass	36,85	86,23	2,34	3,18	October 2024
01/20/2024	Ana	Plastic	45,99	79,1	1,72	1,5	January 2024
10/02/2024	Maria	Glass	13,06	51,2	3,92	3,3	October 2024
08/04/2024	Ana	Steel Cans	19,29	61,73	3,2	3,48	August 2024
08/25/2024	Maria	Plastic	9,35	5,24	0,56	6,16	August 2024
01/18/2024	Ana	Paper	23,12	111,9	4,84	6,41	January 2024
11/11/2024	Carlos	Plastic	46,2	35,11	0,76	7,51	November 2024
08/26/2024	Carlos	Glass	15,72	51,56	3,28	5,19	August 2024
10/28/2024	Carlos	Aseptic Packaging	40,23	52,3	1,3	1,27	October 2024
08/13/2024	Carlos	Aseptic Packaging	22,86	74,75	3,27	2,38	August 2024
10/03/2024	Carlos	Metal Cans	14,35	49,65	3,46	5,81	October 2024
12/26/2024	Pedro	Aseptic Packaging	22,95	96,39	4,2	7,46	December 2024
10/06/2024	Maria	Metal Cans	49,49	238,54	4,82	3,01	October 2024
04/04/2024	Maria	Aseptic Packaging	31,94	108,92	3,41	3,3	April 2024
06/18/2024	Pedro	Plastic	11,94	17,67	1,48	4,23	June 2024
11/20/2024	Carlos	Metal Cans	9,33	28,83	3,09	6,2	November 2024
01/19/2024	Ana	Aseptic Packaging	26,91	58,13	2,16	6,46	January 2024
04/11/2024	Maria	Paper	46,17	133,89	2,9	7,65	April 2024
03/29/2024	Maria	Paper	14,79	19,52	1,32	4,35	March 2024
12/19/2024	Ana	Paper	27,63	44,21	1,6	6,02	December 2024
10/25/2024	Maria	Plastic	15,36	63,74	4,15	1,82	October 2024
05/23/2024	Ana	Metal Cans	25,55	37,81	1,48	4,09	May 2024
04/01/2024	João	Glass	39,98	145,53	3,64	1,15	April 2024
06/25/2024	Pedro	Metal Cans	23,03	14,28	0,62	6,81	June 2024
07/31/2024	João	Paper	27,17	26,9	0,99	7,62	July 2024
02/04/2024	Carlos	Steel Cans	19,61	21,37	1,09	6,44	February 2024
09/08/2024	Carlos	Plastic	22,69	65,35	2,88	1,62	September 2024
04/16/2024	Ana	Plastic	13,09	48,69	3,72	1,32	April 2024
08/23/2024	Maria	Aseptic Packaging	34,59	122,79	3,55	6,07	August 2024

Figure 6. Database, Developed by the authors (2025)

This data served as the basis for structuring the Dashboard, which is essential for the control and management of the cooperative, benefiting both the managers and the collectors.

The Dashboard (Figure 7) presents an intuitive and functional interface, prioritizing simplicity and efficiency in data analysis. It allows dynamic filtering based on three main criteria: time period, type of material, and name of the collector, using predefined lists to avoid manual data entry. The visualizations include a bar chart for total production by type of material and two-line charts highlighting daily production and by collector, with an accessible design and contrasting colors to facilitate interpretation.

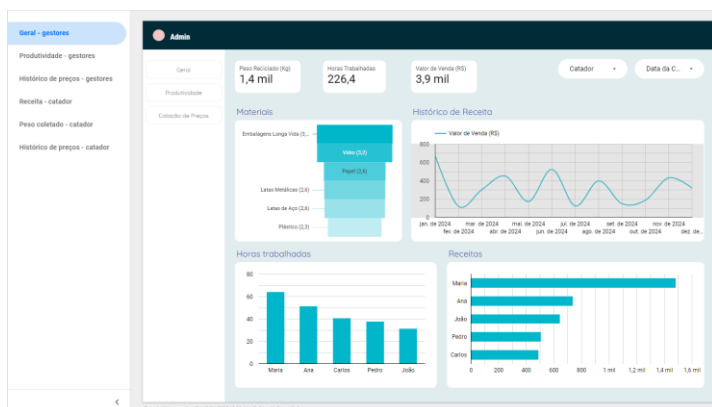


Figure 7. Dashboard, Developed by the authors (2025)

The implementation of the Dashboard in the cooperative optimizes operational management and internal communication, providing a clear view of activities. Data filtering helps identify performance patterns and improvement opportunities, such as determining which materials have the highest production. The "Send Notice" screen speeds up communication about schedule changes and new goals, ensuring that everyone stays informed. In the context of cooperatives, the Dashboard and the integrated communication tools enhance control, transparency, and collaboration, contributing to more efficient management and the achievement of strategic objectives.

5 Conclusion

This study aimed to assist recycling cooperatives in developing an efficient plan for the collection, processing, and management of recyclable products, using integrated analysis and communication tools in Information Systems. Brazil presents a promising scenario for recycling but faces challenges in the integration of public policies and business initiatives. The development of a data management system with a dashboard module that displays operational production data and internal communication facilitates better resource management for production control, through the analysis of key indicators, as well as improvements in internal communication.

Limitations were observed throughout the research, such as the limited number of collectors for the validation of prototypes and the dashboard, the effectiveness of the process of evaluating information by the collectors, and resistance to change observed by the cooperative members. It is suggested as future work to develop strategies for engaging cooperative members and assess the effectiveness of implementing technologies to strengthen recycling cooperatives in the Federal District.

To ensure the continuity of the initiative, an interdisciplinary team of students and teachers is working to implement innovative technologies and encourage entrepreneurship among collectors of recyclable materials during the Egalitarian project.

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Continuing education for teachers in Educational Robotics: Introduction to Programming with Arduino and Micro:bit

Leonardo Mesquita¹, Galeno José de Sena¹, Samuel Euzédice de Lucena¹, Marco Aurélio Alvarenga Monteiro¹, Jânio Itiro Akamatsu¹

¹ São Paulo State University - UNESP, Faculty of Engineering and Sciences, Guaratinguetá, Brazil

Email: leonardo.mesquita@unesp.br, galeno.sena@unesp.br, samuel.lucena@unesp.br, marco.monteiro@unesp.br, janio.akamatsu@unesp.br

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ABSTRACT

This article aims to describe the actions of a project developed at UNESP, Guaratinguetá Campus, Brazil, aimed at training teachers for the public school system in the region of the Guaratinguetá Education Board (DE). The project was developed in partnership with the Guaratinguetá Education Board and included the offering of an Educational Robotics course based on the Arduino and Micro:bit platforms. The emphasis on these two platforms was justified by considering the curricular guidelines for public schools in the state of São Paulo, as well as the availability of platform kits in these schools. An essential aspect of using technologies in schools is to prepare teachers for their use in the classroom. Therefore, the course aimed to complement the level of theoretical and practical knowledge in the area of Robotics of basic education teachers, demonstrating the potential of using robotics for teaching multiple content areas. The actions were conducted according to the guidelines of a Project-Based Learning (PBL) model, aiming to investigate, among other aspects, strategies for the use of PBL in a traditional teaching context. In addition, the actions included the presentation and discussion of topics related to the development of Computational Thinking. The article briefly presents the objectives of the course offered, aspects of its development, as well as the results of its evaluation. The results obtained demonstrate the suitability of this approach for preparing teachers to develop teaching projects with topics of Educational Robotics with their students in their schools.

Keywords: Teacher training; Educational Robotics; Computational Thinking; Arduino; micro:bit.

1 Introduction

This article aims to describe the actions of a project developed at UNESP, Guaratinguetá Campus, Brazil, aimed at training teachers for the public school system in the region of the Guaratinguetá Education Directorate (DE). The project began in 2022 and had the support of the Legislative Assembly of the State of São Paulo, via State Parliamentary Amendment No. 2022.088.38181, for the purpose of funding and investing in the training of teachers for the public school system of the State of São Paulo.

One of the motivations for developing the project is the fact that Basic Education schools have had difficulty changing their pedagogical practices to the new proposal of teaching by skills and competencies, recommended by the new National Common Curricular Base - BNCC (Gerhard & Rocha, 2012). An essential aspect of using technology in schools is preparing teachers for its use. In other words, it is necessary to present, train and provide instructions on when and how to use a given resource in the classroom. The better prepared a teacher is to use a new technological resource, such as Educational Robotics, for example, the more likely they are to be successful in using this tool in the classroom. In this context, it is necessary to redefine certain pedagogical practices to prepare students to face real problems, instead of artificial ones, which are often applied in a decontextualized way in the classroom, giving students a greater role in the teaching and learning process.

The article briefly presents the objectives of the robotics training course offered, as well as the results of its evaluation. The article is organized as follows. In this section, a general presentation of the project is made. Section 2 presents the theoretical basis of the project. The methodology used is presented in section 3. Section 4 describes the development of the project, presenting the objectives of the course offered. Results of the

evaluations of the course by the participants are presented in section 5. Section 6 presents some conclusions and discussions arising from the development of the project.

2 Theoretical basis and related works

The project sought to base its actions in a manner consistent with the BNCC (BRAZIL, 2018), a document from the Federal Government (Ministry of Education) that contains the curricular guidelines that must be followed by basic education schools. The BNCC is based on two premises: the integral formation of the human being and the construction of a more just, democratic and inclusive society.

The BNCC establishes as a goal, for the entire Basic Education path, the development of ten (10) general competencies to be worked on with all students. The emphasis on the use of digital information and communication technologies - ICT, in the different stages of Basic Education, is included in these competencies. For example, competency 5 defends the importance of:

"Understand, use and create digital information and communication technologies in a critical, meaningful, reflective and ethical way in various social practices (including school practices) to communicate, access and disseminate information, produce knowledge, solve problems and exercise protagonism and authorship in personal and collective life." (BRASIL, 2018, p. 9)

It can therefore be seen that the inclusion of Robotics in the educational context is consistent with this competence. Regarding this inclusion, one can initially mention the development of the LOGO language by Seymour Papert and other researchers, which allowed children to control a robotic turtle through computer commands (Massa et al., 2022). The language was developed in the 1960s, when the foundations of computing were still being established. The programming of the robot by children, which was carried out through a computer, made it possible, for example, to draw various geometric figures. Papert was convinced that the machine would be able to change the way children learn, considering that this learning process would occur through the creation, reflection and refinement of ideas. Papert's vision remains relevant to this day, encouraging several schools to adopt methodologies and disciplines that work on this learning process, as is the case of Robotics actions used as instruments to support learning in various disciplines.

In the 1980s, Papert and his research group at MIT began a partnership with the LEGO company, which resulted in the LEGO/Logo system in 1986, which allowed children to build various mechanical artifacts that were connected to an interface and whose movements could be programmed using the Logo language. This system was the first widely available robotics construction kit (Martin et al., 2000).

The inclusion of Educational Robotics in schools must include teacher training programs because, as Reis et al. (2014) point out, it is not enough for schools to have materials such as robotics kits available if there are no trained personnel to use them appropriately in the classroom. The authors also recognize the multidisciplinary nature of Educational Robotics, emphasizing that it is not widely explored by schools, especially public schools, partly due to the costs involved in purchasing the kits, but also due to the lack of trained personnel to use them. In this context, the authors highlight the relevance of establishing partnerships between Universities and schools, as "an important means of introducing educational robotics into primary and secondary education" (Reis et al., 2014, p. 56).

The project developed by Vargas e Silva et al. (2018) also presents a teacher training program aimed at basic education teachers, carried out in 10 3-hour meetings, using the Criatecno CT100® Educational Robotics kit, based on the Arduino platform. The project is part of a university extension program, with training activities being carried out on the university campus (Feevale). The programming of the kit's control board was carried out using the Ardublock language, which is based on predefined blocks. In addition to the training program, the project also included workshops using the LEGO®MINDSTORM® NXT kit, aimed at students in the final years of elementary school and high school students. The workshops could take place both at the university and in schools, with the necessary kits being made available by Feevale.

Da Fonseca Silva et al. (2018) present the results of a survey conducted with teachers at a private Early Childhood Education school that included Educational Robotics in its curriculum. Robotics classes were offered

to students aged 3 to 6 years old, who carried out the activities in groups of up to 4 participants, assembling them using LEGO® kits. In the conclusions of the study, the authors suggest the need for further discussions on the use of Robotics in schools, and highlight, in this context, the need for better teacher training to use this resource in the classroom, thus contributing to more meaningful learning on the part of students.

Pinto et al. (2012) describe the implementation of a teacher training course in Educational Robotics, which is structured in two axes, namely: the technological axis and the pedagogical axis. The technological axis comprises two dimensions, hardware and software, being: (i) hardware – computer, Arduino and electronic components; and (ii) software – environment and application development language for Arduino. The pedagogical axis is structured according to a model designated as the Hierarchical Model of Interactivity in three layers - MHI-3C, which corresponds to the following interaction modalities: researcher-teacher (layer 1), teacher-teacher (layer 2) and teacher-student (layer 3). The proposals for teaching activities and their application in the classroom context occurred in layers 2 and 3. The authors argue, in relation to this form of organization, that "in the context of educational robotics, the role of the teacher is of great importance, acting both in the planning and in the execution of his teaching activity with the resources of robotics" (Pinto et al., 2012, p. 161).

The work of Souza et al. (2016) aimed to analyze the effects of introducing Computational Thinking (CT) in the training of robotics teachers at SESI-PB, Brazil. The project was proposed considering the difficulties presented by teachers and students, mainly in the robot programming stage. Thus, the first phase of the project consisted of offering an introductory course on CT for teachers and students of high school at SESI-PB. The results obtained highlight the need, in the context of Educational Robotics, for teaching CT for teacher and student training. The authors also point out that "there is evidence that CT positively influences student performance" (Souza et al., 2016, p. 1266).

3 Methods and procedures

The methodological approach of the research was based, mainly in its initial phase, on action research (Tripp, 2005), since the actions to be developed were structured jointly with the Curriculum Specialist Teachers - PEC, from the areas of Mathematics and Technology, from DE Guaratinguetá, establishing a link between the university team and the teachers of the schools that would participate in the course. Furthermore, according to Tripp (2005), one of the characteristics of action research is that it is participatory, thus differentiating itself from routine practice (individual) and scientific research (team/collegiate), and also being "collaborative in its way of working" (Tripp, 2005, p. 448). Under this approach, the teachers of the courses should participate in the training activities, propose and carry out teaching projects using Educational Robotics with the students of their schools, supervised by the University team.

The course activities were developed according to the guidelines of a PBL Project-Based Learning model, aiming to investigate, among other aspects, strategies for the use of PBL in a traditional teaching context, and the role of active learning – students participating in the development of projects involving Educational Robotics in their schools – in improving the learning of concepts related to the themes Rational Use of Energy and Energy Efficiency.

The PBL model used was that of the BIE Institute – Buck Institute for Education (www.bie.org) (Markham et al., 2008), which presents PBL as an appropriate model to deal with the educational reality of the 21st century, emphasizing the contextual and interdisciplinary nature of learning. Duch et al. (2006) emphasize that the content to be addressed in a PBL application should aim to develop "higher-level" thinking skills in students, aiming to acquire the cognitive levels established by Bloom's taxonomy: knowledge, understanding, application, analysis, synthesis and evaluation (sense of judgment) (Bloom, 1956, as cited in Duch et al., 2006). This taxonomy was revised in 2001, giving rise to Bloom's revised Taxonomy, in which the cognitive domain categories are: remembering, understanding, applying, analyzing, synthesizing and creating (Ferraz & Belhot, 2010), which should be emphasized in an application of PBL in the current context.

The BIE Institute proposes a PBL model focused on standards (Markham et al., 2008), with the structuring of a project based on the principles described briefly below: (I) Begin with the end in mind: defining, among other aspects, the content standards, key skills and habits of mind that will constitute the expected results of the project; (II) Formulate the Guiding Question: proposing a relevant and meaningful question that will get students involved in the project, requiring them to take an active stance and dedication to seek their own answers and their own knowledge (Pozo, 1998); (III) Plan the evaluation: specify the expected products and artifacts of the project and how they will be evaluated, noting that the evaluation, in a PBL application, is usually based on performance, as it involves a problem-solving activity. (IV) Map the project: includes, among other aspects, the organization of the tasks and activities to be developed, the selection of the necessary resources and the preparation of a visual script (which can be a storyboard or a schedule, among others); (V) Manage the process: describe tools and strategies to assist in managing the development of the project.

4 Justification and development

Preparing teachers to use new technologies in schools, as already mentioned, is an essential aspect, that is, it is necessary to present, train and provide recommendations on when and how to use a given resource in the classroom. After all, the indiscriminate and, in some cases, mechanical use of new technologies may not promote desirable qualitative and quantitative changes in the teaching and learning process. The discussion about the use of a resource in the classroom should emphasize, whenever possible, how it can be used to transmit specific content.

In the proposed course, the content was related to the theme of Energy, with the following focuses: Rational Use of Energy and Energy Efficiency, from the perspective of Robotics, and topics covered in the new curriculum of the New High School of the state of São Paulo, within the Curricular Units planned for schools with the Full-Time Education Program (PEI).

The course was conducted in a hybrid format, that is, in a semi-presential format. The in-person activities were held on Saturdays, from 9:00 a.m. to 1:00 p.m., at the Center for Innovation in Energy Efficiency – InoVEE, located at UNESP – Guaratinguetá campus. The in-person activities were used to develop conceptual content on robotics, as well as to present a model for developing activities, structured in the form of tasks, and general guidelines for developing teaching projects.

Each in-person meeting was held in a technological workshop format, in which the teachers in the course could carry out the proposed activity individually or in pairs, made up of teachers from the same school. The workshops began by introducing, based on the use of problem situations, the topic to be addressed during the activity. The workshop activities enhanced the use of the stages of computational thinking, namely: decomposition, pattern recognition, abstraction and algorithm. Thus, the workshop activities contributed to enriching the training of the teachers taking the course, based on the use of robotics, helping in the development of fundamental skills, such as: logical reasoning, decision-making and creativity.

The project's online activities were developed in 7 (seven) virtual meetings, each lasting 2 (two) hours, aiming to complement the conceptual content presented in the course's in-person activities. In addition to the conceptual content, the training presented topics that were used by the course teachers to develop, together with their students, teaching projects related to the workshop topics.

The online activities were carried out synchronously and asynchronously. In the synchronous mode, the activities were carried out in a "live" format, in which the university team held an online session to answer questions, discussing the solutions to previous exercises provided, and also carrying out reinforcement actions on the content and topics presented in the previous activities. In the asynchronous mode, video classes lasting between 20 and 60 minutes were made available, in addition to complementary materials, such as: handouts, virtual experiments and electronic component manuals. Among the planned online activities, the Virtual Laboratory activities stand out, in which the free simulation software Autodesk Tinkercad™ and Microsoft MakeCode™ software were presented. In both, algorithms were developed for various applications, using programming languages by codes (textual, based on C) or visual (by blocks, based on Scratch™) (Figure 1).

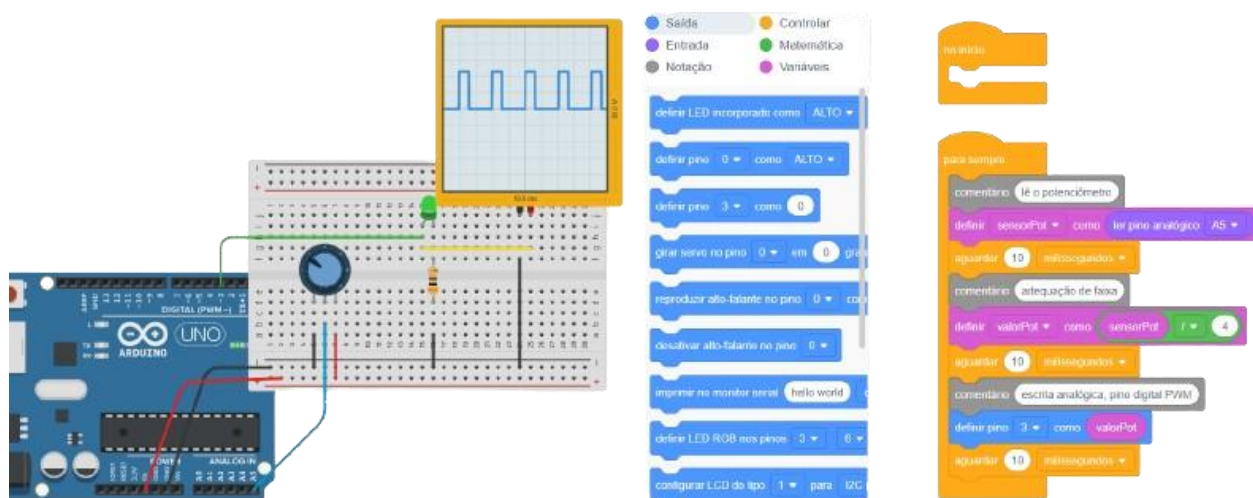


Figure 1: Online activity – Virtual Laboratory using Autodesk Tinkercad™ software.

The use of these languages was important for the participants, as they were able to execute the proposed practices, interact with other participants and, in this way, were able to debug, reuse, test and share several educational robotics projects during the online activities. At the end of each online activity, an Evaluation Form was made available, which had to be answered by the participants within a period of up to 7 (seven) days.

5 Results and discussion

We had forty-six (46) teachers enrolled in the course, all of whom were teachers from the public school system in the state of São Paulo, basic education teachers with classes assigned to Elementary or High School in any component, in 2023, and Pedagogical Management Coordinating Teachers (CGP/CGPA/CGPG). Thirty-three (33) teachers completed the course, indicating that 72% of the enrolled teachers were successful at the end of the course. The students were evaluated based on the development of the proposed activities, during the in-person activities, and through evaluation questionnaires, regarding the online actions carried out in the course.

In the in-person activities, carried out in the format of technological workshops, the teachers in the course carried out several projects, among which we can mention: sequential activation of LEDs, construction of a traffic light, color spectrum, generating tones, reverse sensor, electronic tape measure, measuring temperature, night light, electronic data, compass, among others. In this context, the general skills most highlighted by the participants were: scientific, critical and creative thinking; and, among the objects of knowledge, the most cited were: the use of technology and scientific language, the introduction to algorithms and programming logic, and the fundamental notions of electronic circuits. Therefore, the use of technology in the classroom in a consistent/structured way proved to be challenging, but it was also a motivating factor for future applications by the teachers in their classroom activities. And, finally, we highlight that the project-based approach gave the teachers in the course the opportunity to play an active role in the learning process of the content standards worked with the projects.

At the end of the course, an evaluation instrument was administered to the students, containing questions grouped into two groups:

- Group I: objective questions about the course teachers, teaching materials, approaches used, development of planned actions, both in person and online; these questions about expected results and expectations for the development of activities aimed to assess the degree of agreement of the students with the statements presented, according to a 5-point Likert scale, ranging from 1 = totally dissatisfied / totally disagree to 5 = very satisfied / totally agree.
- Group II: discursive questions, for students to express their opinions on various aspects of the course.

For group I, 15 statements were listed, for which the degree of agreement of the students was verified. As an example, some of the issues are listed below: (a) The theoretical approach of the course; (b) The practical approach of the course; (c) The teaching materials used; and (d) General organization of the course (facilities, teaching materials, platforms, teachers/instructors, etc.).

Considering, in this analysis, the responses to the options "satisfied" and "very satisfied"/"totally agree", it was observed that the students agreed with all the statements, with satisfaction/agreement percentages above 80%. For example, with regard to statement (a), we obtained a degree of agreement of 88.9%; for statement (b), we obtained a degree of agreement of 96.3%; for statement (c), we obtained a degree of agreement of 92.6%; and, for statement (d), we obtained a 96.3% level of agreement.

As mentioned, group II included essay questions in which students could express themselves on aspects related to the development of the course, such as: the aspects of the course that benefited them the most, the points for improvement in the actions developed, and in both cases, these were separate questions for in-person and online activities. Finally, we requested suggestions for improvements in future editions of the course.

Some of the responses from students regarding the positive aspects of the course, for both in-person and online activities, are listed below:

"Knowledge of the materials in practice, option of block programming, ability to clarify doubts."; "Equipment and components; Availability, cordiality and empathy of the instructors; Facilities."; "Practice, Presence of the Instructors (attentive), solving doubts regarding circuit failure." "Contact with the materials; relationship with other professionals; group work."; "Quality practical classes."; "Teaching materials, dedication of the teachers and teaching methods."; "Well-explained content, practical application together with theory, suitable location."; "The attention of the interns and teachers."; "Resources, dedication of the teachers, practical activities."; "Well-prepared material and attention to the students."; "The teaching methods, easy access and use of the classroom."; "Recorded classes by the teacher, provision of handouts, provision of projects through Tinkercad."; "Attentive teachers, self-explanatory classes and complementary activities."; "Easy-accessible digital material; Files available for download; Q&A."; "Online simulation."; "Supplementary activities, teachers attentive to questions and well-explanatory classes."; "Easy to adapt to schedules, easy-to-learn content, assessment activities to monitor progress."; "Q&A."; "Remote classes allowed me to go back to the questions when I had questions to answer the questionnaires."; "The teaching materials, video classes and virtual laboratory."; "Course length; being able to take the course at home; ease of adjusting the course to my routine." "Q&A, material posted in advance."; "Flexible schedule and recorded classes to revisit the content when necessary."; "Quick and concise classes, didactic and with good image quality, aligned with the theoretical part."

Analyzing the responses of the students, regarding what they liked most, it can be stated that the teaching material developed, as well as the preparation and attention given by the responsible team, professors, UNESP/FEG scholarship holders and collaborators, in the execution of the course's training activities, were positive points that facilitated the monitoring of the course activities. The availability of the programming files of the experiments developed virtually, using the Autodesk Tinkercad™ software and the Microsoft Makecode™ software, was also mentioned as a positive point of the course. The availability of robotics, electronic components and measurement materials, so that the students could develop the planned actions (electronic assemblies of the applications) during the face-to-face workshops, was also indicated as being one of the strong points that most benefited the students during the course. Other points positively evaluated by the students were the implementation of a question-answering service, the quality of the video classes and the other materials made available in the Google Classroom virtual learning environment.

To improve the course, we received suggestions to bring forward the posting and availability of teaching materials for the planned online activities, since prior access to these materials could help students with their participation in the question-and-answer sessions. Another suggestion was to increase the number of weekly question-and-answer sessions, since, with the flexible schedules, students would be able to adjust their schedules to participate in these sessions. Finally, they also suggested creating a WhatsApp group to improve and streamline communication between course instructors and students, with a view to providing more support for the planned online activities.

6 Conclusion

We observed that the course aroused great interest among teachers from public schools in the region of the Guaratinguetá Education Board, considering not only the number of teachers enrolled, but also the discussions regarding the possibility of expanding the target audience of the course at a later date. In this context, the organizing team is considering, as potential future works, the possibility of establishing new partnerships between the University and other Education Boards, or even with local governments in the region, with a view to offering new editions of the course, revised and improved, based on the suggestions and criticisms reported by participants in the course already held.

We can highlight, at the end of this project, that teacher training courses, such as the one described in this article, contribute to a better and more efficient use of new technological resources in the classroom by teachers, meeting the curricular guidelines established for basic education in Brazil. More specifically, in the case of the state of São Paulo, the Educational Robotics course meets the need to better prepare teachers to use robotics kits, made available by the State to several public schools, as well as, more specifically, the need to prepare teachers directly responsible for technology-related subjects in schools.

It is also worth noting that the partnership established between the university (UNESP) and the Education Board of the Guaratinguetá region, aimed at training teachers to use new technologies in the classroom, may be beneficial to UNESP itself, since better-prepared teachers will be able to offer better training to their students. This better training, based on new technologies, may contribute to motivating these students to pursue higher education careers in the exact sciences (for example, by opting for Engineering courses), with the potential for them to become students at the university itself in a few years.

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Industry-Community-University-Finance Collaboration scheme for Project Based-Learning of Engineering Education

Hiroshi Hasegawa¹, Kayoko H. Murakami¹, Manabu Ichikawa¹, Kazunori Mano¹, Atsuko K. Yamazaki²

¹ Shibaura Institute of Technology, Systems Engineering and Science Course, Graduate School of Engineering and Science, Japan

² Digital Hollywood University, Graduate School of Digital Contents, Japan

Email: h-hase@shibaura-it.ac.jp

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Abstract

The College of Systems Engineering and Science and the Systems Engineering and Science Course, Graduate School of Engineering and Science have been conducting an industry-community-university collaborative engineering educational program for about 20 years. However, the general attitude on the part of companies, Small and Medium-sized Enterprises (SMEs) which are the majority, in Japan has been that being difficult to approach and they have never considered about industry-community-university collaboration. This seemed to indicate that there might be something wrong with the general scheme of industry-community-university collaboration in Japan.

In this study, instead of using the company's business issues and new business development as research subjects, we introduced them as project subjects and developed a scheme for (1) planning based on system thinking, (2) demonstration experiments and prototyping, and (3) creating innovation by introducing diverse perspectives. A new industry-community-university collaboration scheme was constructed to draw out new business and research elements from the outcome obtained from PBL on this scheme, leading to commissioned and joint research. Using this scheme, the Special Exercises in Systems Engineering (SE2), the Cross-Innovation Project (CIP) and the Cross-cultural Engineering Project (CEP) were performed on PBL. In FY2024, 30 projects were executed in SE2 and in CIP, 13 projects, including one entrepreneurship project, were executed including 10 projects that were continued from SE2 in CIP. To create innovation through diversity and the introduction of new perspectives, CEP@Portugal (FCT NOVA and University of Minho, Portugal) was combined for SE2 projects and CEP@SIT for CIP projects. The scheme was verified and validated by outcomes of SE2, CIP and CEP using this scheme. The results obtained are presented in this paper.

Keywords: Project-Based Learning, Engineering education, System Thinking, Generic Skills, Innovation

1 Introduction

The Age of VUCA has long been recognized after various world affairs. In addition, with the digitalization, robotization, and democratization of AI in recent years, Joseph Aoun, President of Northeastern University, has suggested that Higher Education in the Age of AI requires education in systems thinking, critical thinking, entrepreneurship, and cross-cultural agility (Joseph, 2018).

Furthermore, to create new value, innovative creation is needed. The framework for innovative creation has changed dramatically from the old linear system that transferred science to technology and then deployed the outcome into business. And then, in an innovative ecosystem, technologies deployed from science are combined and transformed into business, and the returns from its commercialization are invested in the combination of technologies. Such an ecosystem has been required, however, now, the accelerating speed of research and development through AI, computing, and digitalization has brought science, technology, and business into close-proximity. Therefore, a strategic response is required, as shown in Figure 1, to develop frontier markets by investing not only in combination of technologies but also in the science of its advancement (METI, 2025). This strategic response is not a closed strategy to be carried out individually by the government, industry, universities, and financial institutions, but a collaborative process among these institutions based on

open innovation. The close-proximity of science, technology, and business (Figure 1) cannot be achieved with the old research and development scheme, thus requiring a change of a mindset in which science and technology research domain are crossed business domain, i.e., including business models. However, the realization of this close-proximity scheme is not easy.

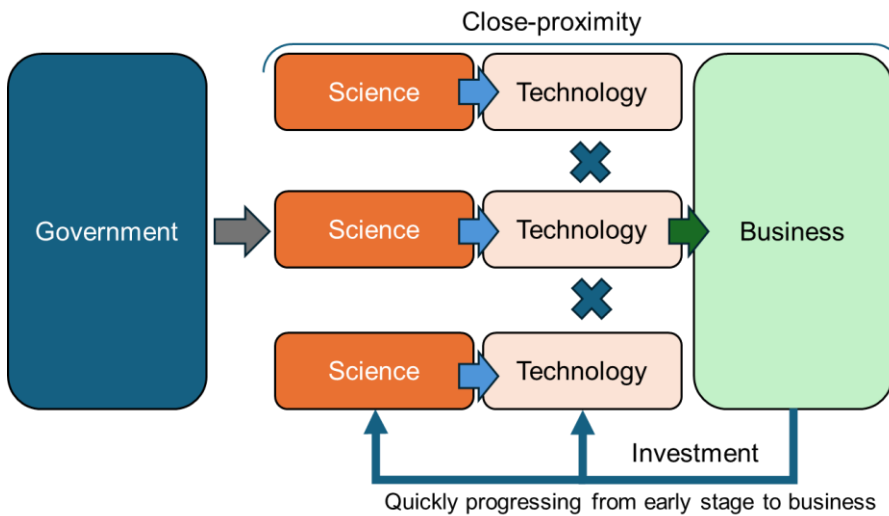


Figure 1. Strategic response for development of frontier markets (METI, 2025).

On the other hand, the government suggests that this scheme requires the industry-community-university-finance collaboration based on open innovation for acceleration. With this background, each university is building an open innovation environment, and Shibaura Institute of Technology has launched the Bay area Open innovation Center (BOiCE) in Tokyo Bay area. It provides Open Laboratory Innovation, Open Learning Innovation, Open Social Innovation, Open Resource Innovation, and Open Field Innovation. Under this environment, universities in the science and technology (research institutions) are expected to contribute to society, and if the science and technology that acts as seeds match the needs of the business domain, collaboration is expected to advance.

However, this matching is difficult, and according to those working in the area of industry-academia-government collaboration, only about 10-20% of all academies they know are active in industry-academia-government collaboration (Maenami, 2013). In addition, large and global companies have MOUs with universities, while Small and Medium-sized Enterprises (SMEs), which are the majority, have not progressed well as indicated by the mutual recognition between industry, academia, and government that hinders industry-academia collaboration (Nagata, 2006), and even now there is no significant difference. In addition, the matching of engineering education between universities and industries is matched as a whole but mismatched in a lot of threads (Wakabayashi, 2018).

In this study, instead of using the company's business issues and new business development as research subjects, we introduced them as project subjects and developed a scheme for (1) planning based on system thinking, (2) demonstration experiments and prototyping, and (3) creating innovation by introducing diverse perspectives. A new industry-community-university collaboration scheme was constructed to draw out new business and research elements from the outcome obtained from Project Based-Learning (PBL) on this scheme, leading to commissioned and joint research. This paper describes the development of industry-community-university-finance collaboration scheme as an engineering education-based scheme based on strategic responses for frontier market development in Chapter 2, case studies of PBL using the developed scheme in Chapter 3. and the findings obtained in Chapter 4.

2 Industry-Community-University-Finance Collaboration scheme

In order to realize a strategic response to the development of frontier markets (Figure 1), it is important to search for science and technology to quickly progressing from early stage to business and to match them with research institutions in that field. However, few researchers are collaborating with industry-academia, and there is actually a mismatch between the objectives of the company views and those of the academia views, as shown in Figure 2. This is thought to be a fundamental problem in that matching is performed for the specific objectives, i.e., specific solution, of both sides. Therefore, we have to solve this mismatch problem. If this problem is not solved, it cannot be considered to be a fundamental solution.

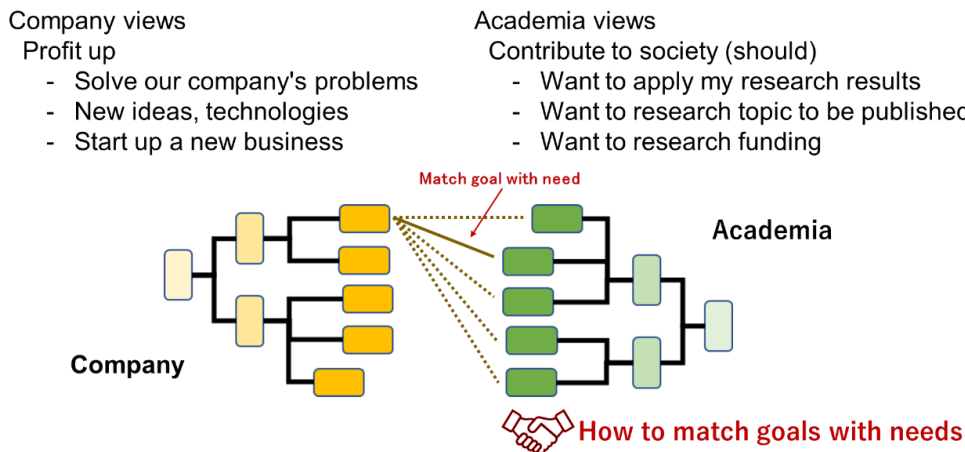


Figure 2. Conflicts between companies and academic researchers

2.1 From research-based strategy to engineering education-based strategy

For solving this fundamental problem, we reversed the strategic response scheme for the development of frontier markets based on the research (Figure 1) and developed a strategic response scheme based on engineering education, as shown in Figure 3, in which problem discovery based on multi-national and multidisciplinary PBL is carried out together with the business side. In this scheme, the project activities are conducted by multi-national and multidisciplinary members to identify problems with the business side's major objective as the problem. And the system planning that will be the solution is created by a mixture of science and engineering students considering cross-cultural agility, as shown in the figure 3.

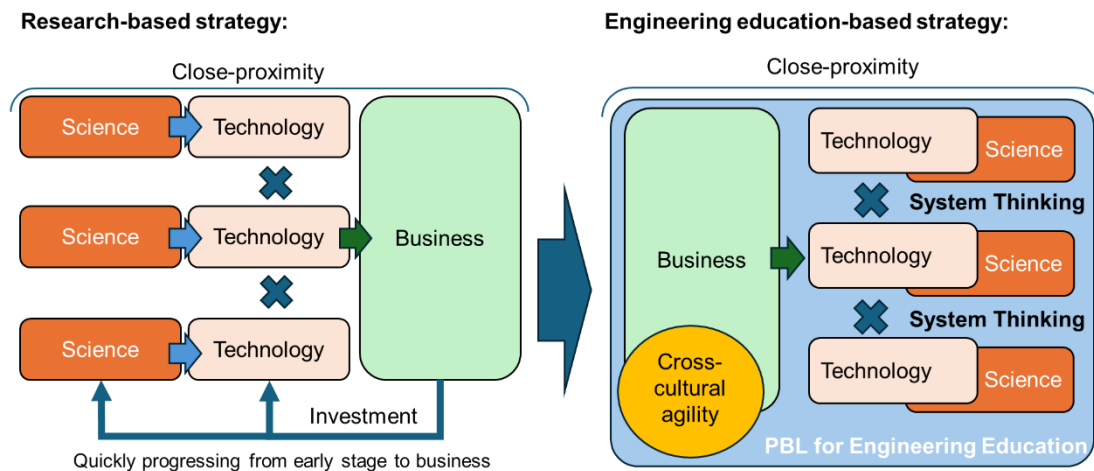


Figure 3. From research-based strategy to engineering education-based strategy for change of a mindset in which science and technology research domain are crossed business domain

The knowledge and experience that will form the basis of this project activities are acquired based on the System thinking Engineering education program (SE education program) shown in Figure 4.

This SE education program starts with the Workshop of system-thinking and consists of lectures and exercises of Systems Engineering A and B, which are the required subject of the undergraduate school. And, in the graduate school, System Engineering, which lectures on entrepreneurship based on system thinking, and Special Exercise of Systems Engineering (SE2), which proposes system planning to solve real world problems, are required subject. The knowledge and experience obtained through this SE education program are developed into the culminating Cross Innovation Project (CIP) (Mochizuki, 2020) and Cross-cultural Engineering Project (CEP) (Navas, 2020, Kongwat, 2021, Hasegawa, 2023 & Otsuka, 2024). In CIP, demonstration experiments and prototyping based on the planning proposed in SE2 are conducted, and in CEP, a multicultural and multidisciplinary PBL, projects are brushed up from a cross-cultural agility and global viewpoint. In this way, knowledge and experience are consolidated as Generic Skills through step-by-step repetition of exercises and lectures.

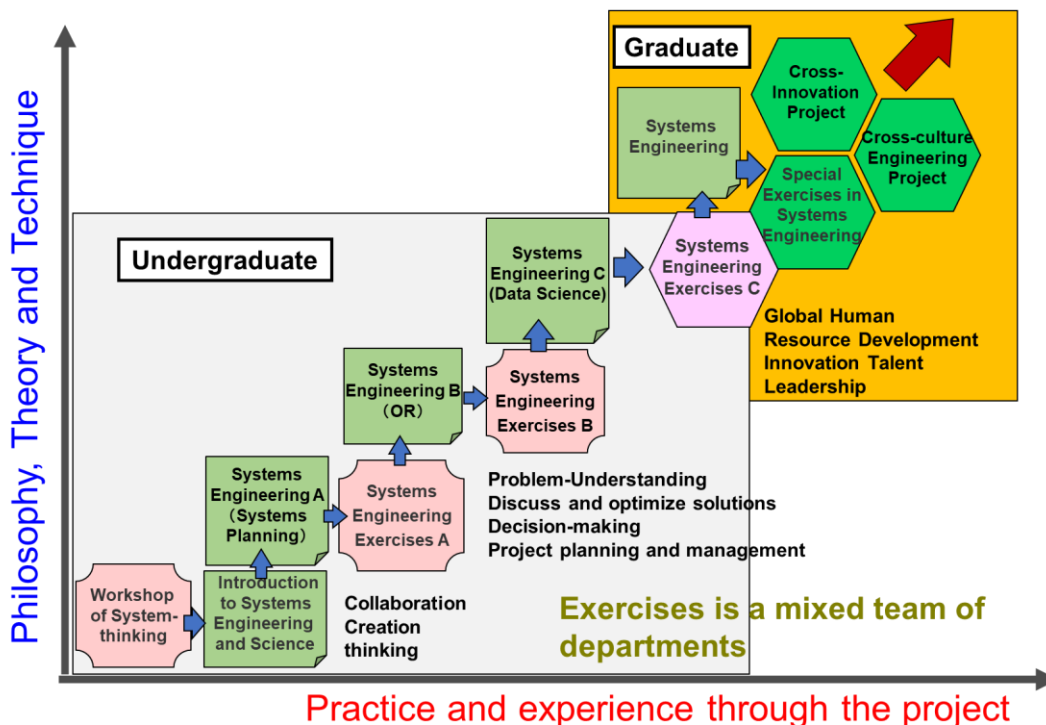


Figure 4. System thinking Engineering (SE) education program

2.2 Development of collaboration scheme

The industry-community-university-finance collaboration scheme developed based on the concept of the engineering education-based strategy (Figure 3) is shown in Figure 5. This scheme is applied in SE2, CIP, and CEP, which are the culmination of the SE education program.

As shown in Figure 5, instead of matching university research seeds with management issues and new business development in industries and communities, a project exercise of SE2 is started with the problem finding and clarification of tasks through system thinking. In the SE2 project teams with a mixture of different disciplines, after clarifying tasks, the team members generate ideas and make proposals for system planning. At the time of system planning in these projects, innovative creation from different viewpoints will be conducted with EU

students at CEP@Portugal (FCT NOVA and University of Minho, Portugal) to brush up the system proposals, will be proposed as the final system planning.

In the following CIP, innovation and global viewpoints will be reflected in the project in the same way by crossing CIP and CEP@SIT with mixed overseas students. By taking these various perspectives into consideration in prototyping and demonstration experiments, attractive solutions will be derived.

New businesses and research elements are extracted from the project outcomes through this scheme and are transformed into new businesses and lead to commissioned joint multidisciplinary research.

Through the reversal approach described above, we will try to develop frontier markets for the creation of new value through business, science, and technology close-proximity.

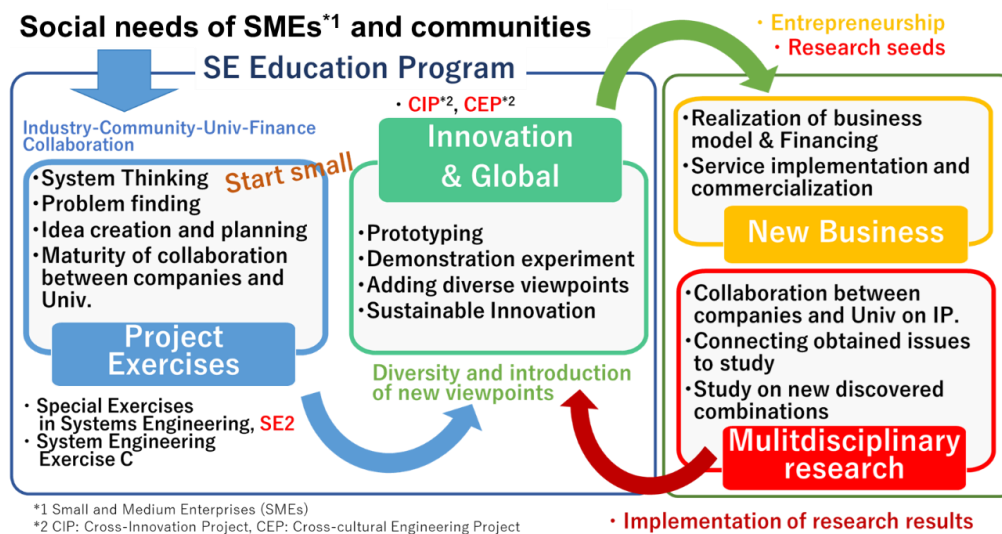


Figure 5. The Industry-Community-University-Finance Collaboration scheme.

3 Case studies of PBL based on developed scheme

3.1 Consideration of number of the provided issue

We implemented a multidisciplinary type's PBL using the development scheme to solve problems based on the social needs of SMEs and local communities. Figure 6 shows the number of provided issue in FY2022 before the scheme was developed and the number of provided issue after the developed scheme was applied every year. The number of issues is shown for large and global companies (LGCs), SMEs, communities (COMMs), and financial institutions. In addition, as an entrepreneurship education, an entrepreneurship project (ENTRE PJ) was started in FY2023, which is a project with a theme that combines the leader's motivation and social contribution. The number of ENTRE PJs is also included in the figure.

First, the number of provided issues to SE2 (required subject) shows that many SMEs, which previously considered it difficult to provide issue for industry-university collaboration, have started to provide many issues. In addition, LGCs have started to apply the issues following the SMEs. There was no increase or decrease in the number of regional issues, depending on whether or not a developed scheme was introduced. On the other hand, financial institutions have changed their style from themes related to their own issues and events to providing issues of SMEs that they support. It is believed that this change in style is due to the fact that financial institutions are now considering that industry-university-finance collaboration can be used as a sales tool.

Next, CIP, is elective subject, was performed 12 projects including two entrepreneurship projects in FY2023. Nine of these projects were carried over from SE2. In FY2024, 30 projects were carried out in SE2 and 13 projects in CIP that consisted of one entrepreneurship project and 10 projects from SE2. Since CIP is an elective subject, the total number of provided issues remains unchanged.

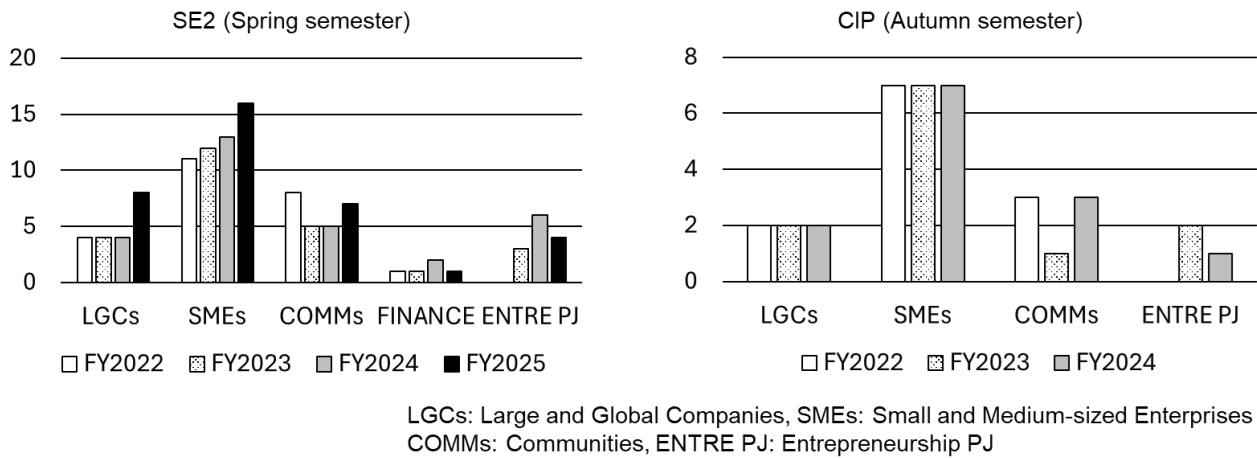


Figure 6. Number of provided issue under the developed scheme. In FY2022, number of provided issue before the development of this scheme.

3.2 Case study of SE2 and CEP collaboration

As a case study of this scheme, the outline of the Nasu Area Innovation Project is described. This project is a tourism service called KANKO, which uses technology to realize the aroma of tourist attractions in Nasu Town, Tochigi Prefecture, where the emperor's official residence is located, so that tourists can visit the places where they can smell the aroma.

The refinement of the scent and this concept creation was completed by the second design review (DR2) in SE2, and how to realize the circulation process using the scent and the business model were conducted at CEP@Portugal (FCT NOVA) together with EU students. Based on outcomes of CEP@Portugal, project team proposed a system planning at the Final Presentation (FP) of SE2. A sustainable proposal was made to develop a capsule toy using scents extracted from Nasu's natural resources and wastes. A business model was proposed that would not only be enjoyed by tourists, but would also benefit the businesses in Nasu, and boost Nasu as a whole.

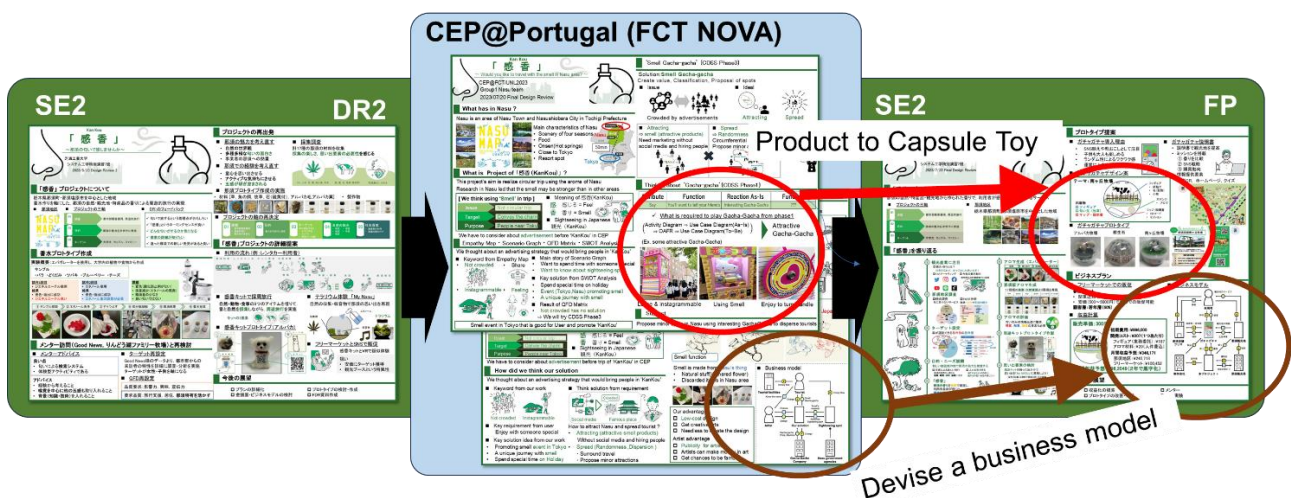


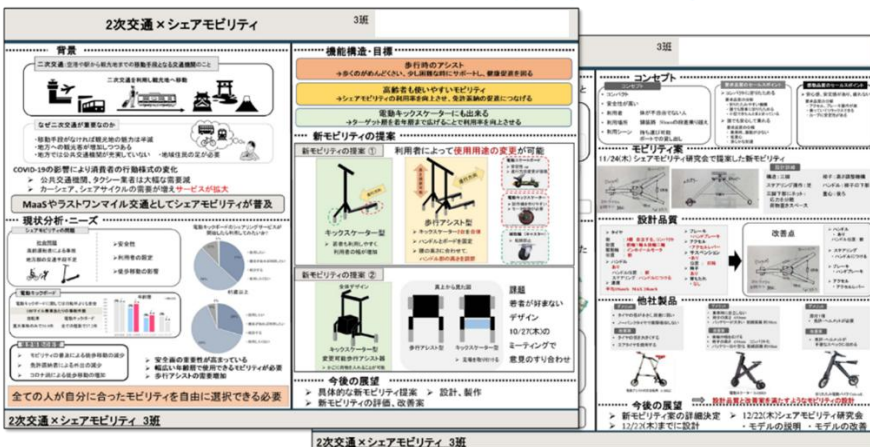
Figure 7. Case studies of SE2 and CEP collaboration: KANKO, Scenting Project.

This system planning was demonstrated in CIP in autumn semester. The scents were productized using wax art, and then the scent was based on the three themes of hot springs, nature, and coffee, which are Nasu's strengths, and a total of six tourist spots were proposed. A total of 240 capsule toys were prepared, and all 240 were distributed in two days. With the successful results of the project up to this stage, they participated in the 4th business competition sponsored by a company and won the third place. Based on this project outcome, they are planning to launch the first aroma business in July 2025, together with a company in Nasu Town.

3.3 Case study of CIP and CEP collaboration

This project is a shared mobility project for the realization of a secondary transportation system (Last one mile) for tourism areas. The shared mobility was conceptualized through the first and second design reviews of the CIP, and then, in CEP@SIT (multi-national and multidisciplinary PBL with industry-university collaboration held Shibaura Institute of Technology in Japan), they were visited in the target tourism spot, Nasu area, to brush up the use cases. And a 3D printer was made a scale model of the obtained conceptual design. After confirming the behaviours using this scale model and calculating the strength using CAE, a prototype was manufactured together with SMEs, and the manufactured prototype was exhibited at an exhibition hosted by Saitama Prefecture. Driving experiments using this prototype and detailed studies using multi-body dynamics simulations revealed the need for further improvements and design studies. This project activity was the launching for shared mobility research with SMEs.

CIP: Demonstration experiment and prototyping: Planning



CEP@SIT: Demonstration experiment and prototyping: Planning

Project outcomes: Prototype on exhibit

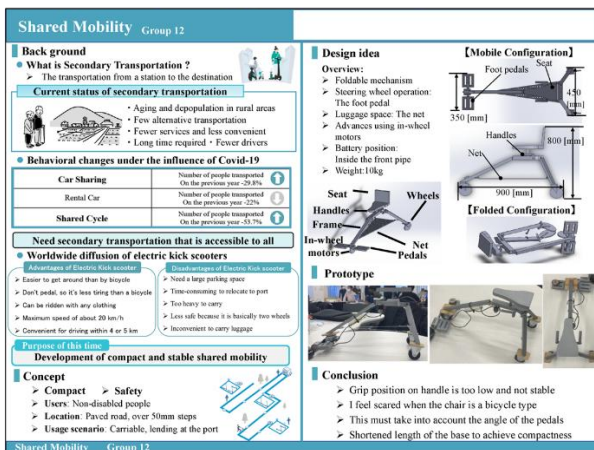


Figure 8. Case studies of CIP and CEP collaboration: Shared mobility project.

4 Conclusion

In this paper, a new scheme for industry-community-university-finance collaboration is developed. This scheme corresponds to a strategic response to develop frontier markets. The strategic response is usually a research-based strategy, and industry-university collaboration schemes in the close-proximity of business and science and technology have various difficulties in matching research seeds and business needs.

To solve this difficulty, we applied reverse thinking and combined PBL with engineering education to devise an engineering education-based on strategy. Based on this strategic response, an industry-community-university-finance collaboration scheme was developed. By using the developed scheme, the following outcomes were confirmed:

- The number of provided issues by SMEs increased drastically compared to when the scheme was not adopted. In FY2025, there were some cases where companies that wanted to offer provided issue was rejected.
- The scheme indicated that it is possible to find problems, conduct demonstration experiments, and make them into businesses through the implementation of project activities.
- In the same way, the need to start with project activities, develop prototyping, and then improve and explore new designs occurred, leading to joint research with SMEs.

In the future, more robust empirical data, such as measurable educational and business outcomes, and comparative analysis with traditional university-industry collaboration models will be conducted to clarify the effectiveness of this scheme.

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Faculty Development for Engineering Professors: A Course Integrating Active Learning and Digital Technologies

Elisa Boff¹, Dianne Magalhães Viana², Laurete Zanol Sauer¹, Liane Ludwig Loder³, Valquíria Villas-Boas³

¹ University of Caxias do Sul, Brazil

² University of Brasilia, Faculty of Technology, Brazil

³ Federal University of Rio Grande do Sul, Brazil

Email: eboff@ucs.br, diannemv@unb.br, lzsauer@ucs.br, lianeludwig@ufrgs.br, vvillasboas@gmail.com

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Abstract

This paper synthesizes the authors' years of experience in training university faculty, particularly those teaching in Exact Sciences and Technology. It presents the theoretical foundations of the pedagogical approaches adopted in these training programs, emphasizing learning theories that guide the development of didactic strategies to promote meaningful learning. Additionally, it discusses the use of digital resources as essential tools for planning innovative teaching practices in both in-person and virtual environments. Within this context, the paper presents a teacher training course developed and implemented at the authors' institutions, designed to be replicable across higher education institutions. The course aims to empower professors to create and deliver learning environments in both in-person and online education, integrating theoretical foundations, active learning, and technological mediation.

Keywords: Active Learning; Teacher Training; Faculty development; Educational Technology.

1 Introduction

In recent years, particularly since 2019, due to the new curricular guidelines for undergraduate Engineering programs (Brasil, 2019), many Engineering schools have been facing the pedagogical challenge of training their faculty to shift their teaching paradigms, from a directive pedagogy, which emphasizes content transmission, to a teaching process focused on the development of skills and competencies, where the professor acts as a facilitator and students become the central agents of the learning process.

Reflecting on the training of engineering educators first requires an understanding of teaching in higher education more broadly, as well as of the current contexts and conditions under which university faculty work. The French university model, implemented in Brazil in 1808 with the arrival of the Portuguese royal family, contributed to shaping a teaching profile focused on professional expertise, where teaching consisted mainly of delivering lectures or presentations on specific subjects (Masetto, 1998). As a result, to this day, most Brazilian university professors are highly qualified and are master's and doctoral degree holders in their fields of expertise, yet they become teachers more by circumstance than by intentional preparation. In the specific case of engineering education, what we often see is an engineer-who-teaches, rather than a professionally trained engineering educator (Villas-Boas, Booth, Mesquita, & Lima, 2016, p. 484).

It is evident that, for many instructors, adopting an innovative pedagogical practice remains a significant challenge. This transition requires overcoming the barriers of "certainties," centralized "attention," and the notion of knowledge as "consolidated" and solely held by the teacher. However, in an era of connectivity, where knowledge is constantly being constructed and renewed, the learning process must be intrinsically linked to innovation, interaction, collaboration, discovery, and to strategies and methods that view students' questions as potential starting points for knowledge construction.

(Re)thinking teaching and learning processes, with an emphasis on the quality of professional and civic education of future engineers in Brazilian Engineering schools, is an urgent task. Otherwise, we risk contributing to the training of underqualified professionals, whose knowledge and practices may be inadequate in the face of rapid advancements in the world of work. A clear example of this can be seen in many undergraduate Engineering programs in the country, where, despite the new National Curricular Guidelines, the design of curricula and courses, as well as lesson planning, still fail to incorporate competency-based education, active learning strategies and methods, and the increasingly abundant technological and digital resources available.

Considering this reality, this paper presents a teacher training course developed and implemented at the authors' institutions, designed to be replicable across higher education institutions. The course aims to empower professors to create and deliver learning environments in both in-person and online education, integrating theoretical foundations, active learning, and technological mediation.

2 Theoretical Framework

An effective teacher training program must be grounded in processes of reflection in, on, and for pedagogical practice within the teachers' contexts of professional activity. This approach aims primarily to enable teachers, by learning to act and reflect on their actions, to develop a habit that facilitates the rupture with the traditional paradigm, one based on certainty in knowledge and practice. Within this perspective, pedagogical knowledge becomes a priority and an essential component of teacher education.

Regarding reflection, Ghedin (2005) proposes a transition from the epistemology of practice, as outlined by Schön (1992), to an epistemology of praxis, "since praxis is a movement operationalized simultaneously by action and reflection; that is, praxis is a final action that contains, within itself, the inseparability of theory and practice" (Ghedin, 2005, p. 133). For the author, the process of reflection must not be confined to the classroom but should also consider the historical and cultural conditions that shape the educational context, and the individuals involved in the formative process.

Thus,

A process of critical reflection would allow teachers to move forward in transforming their pedagogical practice through their own transformation as critical intellectuals. This requires becoming aware of the ideological values and meanings embedded in teaching practices and institutional structures, and engaging in transformative action aimed at eliminating the irrationality and injustice present within these institutions [...]. Critical reflection calls for a critique of the internalization of dominant social values as a way of becoming aware of their origins and effects. (Ghedin, 2005, p. 139).

It is also important to emphasize that

The pursuit of competent pedagogical practice, with higher-quality teaching, new alternatives for university-level instruction, and paths that lead to the construction and production of knowledge that go beyond the arrogance of crystallized knowledge, along with the implementation of experiences that seek to create new forms of teaching and research, are challenges demanded by the requirements of modernity. (Corteletti, Ribeiro, & Stedile, 2002, p.15).

Reflective practice enables teachers to engage in self-assessment of their beliefs and daily pedagogical practices, leading to changes in posture and interactions with different fields of knowledge, as well as to the problematization of the educational act. It serves as a means of empowering teachers to become protagonists responsible for guiding their teaching practice, rather than merely executors of predetermined tasks. Reflective practice values the teacher's tacit knowledge, not solely their academic knowledge, and recognizes the development of teaching practice as a continuous process to be refined throughout their professional life.

2.1 On Pedagogical Knowledge

In their teacher training process, professors must identify and understand their conceptions of learning, whether empiricist, aprioristic, or constructivist (Becker, 2012) and take a reflective stance toward them. Learning conceptions strongly influence the design of educational environments, whether in-person or remote, as well as the use of technology and digital resources. Creating learning environments where students are given space to act, analyze, discuss, problematize, and engage in the construction of their knowledge is a recurring theme in discussions surrounding the new National Curricular Guidelines for Engineering programs in Brazil. Considering the challenges faced by the academic community in keeping pace with the development of educational technologies while maintaining the quality of teaching and learning, we must find ways to better understand and explain the learning process, one that considers physical, biological, mental, psychological, cultural, and social aspects. To this end, it is essential, first and foremost, that educators have a clear understanding of their concept of learning, as it is this foundation upon which the learning environment is created, whether in face-to-face, blended, distance, or online courses, with or without the use of digital technologies and resources.

According to Elmôr-Filho, Sauer, Almeida, & Villas-Boas (2019), within the empiricist conception of learning, we find behaviorist psychology, represented by authors such as Watson and Skinner, whose explanation is based on the idea of conditioning, that is, learning is seen as a modification of behavior triggered by an external stimulus from the teacher to the learner. In this perspective, pedagogical practices are teacher-centered and rely on content transmission and control, aiming to produce systematic and operational changes in the environment and the teaching approach to increase the likelihood of desired responses. The student, in turn, is passive in the process, acting only in response to external stimuli provided by the teacher or the environment, and knowledge is understood as a sequence of stimuli and responses. This conception does not address the learner as a subject nor consider their entanglements, activities, or implications within the learning process.

The apriorist conception, represented by Gestalt psychology, particularly the work of Max Wertheimer, Köhler, and Koffka, places strong emphasis on perception and explains learning, according to Hilgard (1973), as something that occurs suddenly, through insight, based on an innate, a priori capacity that the individual inherently possesses. According to this theory, human perception is not merely the sum of sensory data but undergoes a process of restructuring that forms a unified whole, a *Gestalt*; it is not a collection of elements, but rather structured units, where the whole is greater than the sum of its parts. In this view, pedagogical practices, although seemingly learner-centered, are designed to allow insight to emerge through structured activities that highlight meaningful aspects to be perceived. Despite implying active engagement from the learner, the structure itself is predetermined and simply needs to be activated in a specific way.

From a theoretical standpoint, teacher training should also be underpinned by knowledge that serves as a foundation for teaching practices. Notable examples include Edgar Morin's Theory of Complexity (2002), Maturana and Varela's Biology of Knowledge (2001), and Piaget's Genetic Epistemology (1983), among others. These theoretical frameworks offer new perspectives emerging from scientific thought for investigating language, learning, and knowledge construction. They also establish a clear connection between cognition, learning, and life.

According to Bordenave and Pereira (2001, p. 28), "learning is the set of mechanisms that the organism activates to adapt to its environment." These authors highlight as a key point that:

in this same sense, it can be inferred that learning is an integrated process in which the whole person (intellect, emotions, muscular system) is organically engaged. In other words, learning is a qualitative process through which the individual becomes better prepared for new learning experiences. It is not, therefore, a quantitative increase in knowledge, but a structural transformation of the person's intelligence. (Bordenave & Pereira, 2001, p. 25).

According to the aforementioned authors, we can infer that learning depends on certain conditions to take place: the presence of a problem to be solved, which demands the engagement of an individual motivated to resolve it, thereby triggering attempts at action that bring them closer to their goal and to the learning objects defined by the contours of the problem. Furthermore, each new learning experience relies on prior knowledge, on solutions that have already been developed and internalized. Throughout this process, we observe that, in addition to cognitive aspects, individuals — learners — undergo emotional processes. Emotions such as curiosity, tension, anxiety, enthusiasm, frustration, and joy, among many others, influence the process of acquiring knowledge, retaining it in memory, studying, observing, experiencing, and receiving feedback, all of which contribute to the structure of the learning process.

Contributions such as Vygotsky's (Pellegrino, 2000, p. 38) emphasize this conception of learning, as "human beings construct knowledge through history and culture, based on interactions with others and with the reality in which they live." Rogers also reinforces the learner's interaction with the environment, asserting that in today's world, change is constant, and thus it becomes necessary to facilitate both change and learning. For Rogers (1969 apud Bordenave and Pereira, 2001, p. 47), "[...] the only educated person is the one who has learned how to learn, how to adapt to change; the person who has realized that no knowledge is secure, and that only the process of seeking knowledge provides a basis for security."

In this context, Masetto (2012, p. 45) states that the learning process should be understood as "a process of growth and development of the person as a whole, encompassing at a minimum four major dimensions: knowledge, emotional-affective, skills, and values-based attitudes."

Based on these conceptions, teaching activities can promote active participation and engagement through the formulation of problems to be discussed collaboratively by those who are motivated and willing to construct their learning paths. Transforming the traditional classroom, which is characterized by low levels of student participation, an emphasis on solitary activities, mechanical content learning as the primary goal of teaching, and the mere "distribution" of knowledge, depends on several factors. However, the most critical factor is the willingness of both teachers and students to recognize and agree on the benefits of such changes. These transformations require a significant revision of both the teacher's and the student's roles.

Constructivist approaches have increasingly advocated for the teacher's role as a guide, questioning, reasoning, accepting constructive suggestions, rejecting negative attitudes, and valuing all responses. At the same time, they emphasize attitudes such as respect, generosity, humility, courage, and trust. The goal is to shape a curriculum that considers students' questions and interests, transforming it into something meaningful and fulfilling for them. As active agents in the process, students must engage and recognize the benefits of their participation.

When the teacher sees themselves as a mediator between the student and the object of knowledge, they use content and strategies to facilitate this mediation. But more importantly, they understand it as a personal relationship involving two human beings interacting, influenced by all possible socio-emotional as well as technical dimensions. This gives rise to the need for empathy between the actors in the process, which is essential for understanding and respecting the other person's challenge. Such empathy is vital to the success of the mediation process, fostering a genuine connection between both parties regarding the goals of learning. With a focus on intentionality and reciprocity, this connection enables the emergence of all other necessary elements throughout the learning process, where teacher and student act as co-constructors of realities that interpenetrate and generate new knowledge for both.

2.2 Online, Remote, and Hybrid Education, Technologies, and Digital Resources

The COVID-19 pandemic, which physically separated students, families, and citizens around the world from 2020 to 2022, compelled schools and universities to (re)plan their activities to bring the classroom environment into the homes of confined students. The digital transformation in education, driven by the demands of the pandemic context, incorporated elements from the historical evolution of teaching and learning processes mediated by digital technologies.

Despite the technological possibilities that support the development of new distance learning models grounded in constructivist and socio-interactionist approaches to education, instructional and self-study-based models remain widely disseminated today.

When referring to Distance Education, we follow the definition provided in Decree No. 9.057, which considers distance education as:

an educational modality in which the didactic-pedagogical mediation in teaching and learning processes occurs through the use of information and communication technologies, involving qualified personnel, access policies, monitoring and appropriate evaluation, among other elements, and through which educational activities are conducted by students and education professionals located in different places and at different times. (DOU, 2017).

Currently, educational environments are being designed for both in-person and distance modalities. In Brazil, legally, only these two modalities are formally recognized. However, especially during the pandemic period, we have witnessed the emergence of a broader range of pedagogical approaches mediated by digital technologies. In this context, it is necessary to establish conceptual distinctions between Distance Education and Online Education. Distance Education is an alternative modality to in-person learning, while Online Education is a didactic-pedagogical approach and a phenomenon of cyberculture (Pimentel, & Carvalho, 2020). Online Education consists of a set of teaching-learning actions or curriculum practices mediated by digital interfaces that enhance interactive and hypertextual communicative practices (Santos, 2009).

In 2020, due to the COVID-19 pandemic, many educational institutions adopted the model of "Remote Teaching," consisting of real-time classes delivered via video or web conferencing platforms. By 2021, institutions began transitioning to a format in which in-person classes are simultaneously broadcast to students who are unable to be physically present. This format has come to be known as "Hybrid Teaching," although this terminology is still debated among experts.

Online Education can encompass all these forms of technology-mediated instruction as well as both formal modalities, in-person and distance learning. Within the in-person modality, part of the activities and collaboration between students and teachers may extend into cyberspace, using apps or the institution's Virtual Learning Environment (VLE).

In Pimentel and Carvalho (2020), the "Principles of Online Education" are presented to propose alternative didactic-pedagogical practices for both the in-person (with technological mediation) and distance learning modalities. These principles are interconnected, interdependent, and form a coherent set of conceptions and actions necessary to implement Online Education effectively. For instance, collaborative learning cannot be fostered without genuine dialogue; to promote collaboration and co-authorship, active teacher mediation is essential; authorial activities only make sense when knowledge is conceived as an open work, among other key relationships.

Within the context of Online Education, collaborative practices can be mediated by software that enables cooperation, communication, and coordination. For each of these three dimensions of collaboration, there are both free and commercial applications available to support educational activities in in-person classrooms

(using computers or mobile devices) or in remote learning scenarios (where students are geographically dispersed but connected via the internet). Teachers must be familiar with these technologies in order to integrate them into their instructional planning and adopt active learning strategies mediated by digital technologies. In doing so, it becomes possible to enhance the learning process through interaction and authorship.

3 The Teacher Training Course

We present below a proposal for a teacher training course, based on the training courses offered at the authors' institutions. As previously mentioned, the purpose of the course is to equip engineering faculty to design and facilitate learning processes in both in-person and online environments, integrating theoretical foundations, active learning strategies, and digital mediation. The course addresses a critical gap: most engineers who transition to academia lack formal pedagogical training, and many experienced faculty members still struggle to design online classes that are both conceptually rigorous and pedagogically coherent. Therefore, the course syllabus was designed to meet these needs and is grounded in the theoretical framework detailed in Section 2.

The proposed course aims to: discuss aspects related to contemporary teaching practices and student learning in different contexts; create conditions for participants to learn about the characteristics of distance learning and face-to-face learning modalities mediated by digital technologies; characterize the distance learning modality in terms of its foundations, policies and actors involved; provide participants with the tools to plan, develop, and reflect on pedagogical practices mediated by digital technologies, as well as to practice the use of digital tools and the institution's virtual learning environment; and be easily replicated in any higher education institution.

The course was designed using the flipped classroom pedagogical approach, in which participants will engage with readings, video lessons, and podcasts available on the course's Virtual Learning Environment (VLE) prior to the live sessions, in order to support the practices to be developed during class time. To ensure that participants experience active learning strategies throughout the course, the topics addressed in the synchronous meetings will incorporate various techniques such as Peer Instruction, Minute Paper, Jigsaw, and Think-Pair-Share, using free software tools to support the activities, such as Socrative, Mentimeter, Google Drive for collaborative texts, and breakout rooms in the web conferencing platform.

Table 1 presents the structure of the eight sessions, which can be offered in a synchronous format using web conferencing software such as Google Meet, Microsoft Teams, or Zoom. Each session lasts 2 and a half hours.

Table 1. Topics to be addressed in the sessions of the proposed course.

Synchronous session	Topics covered
1	Foundations of Distance Education and Online Education.
2	Planning online courses in light of the foundations of Distance Education, Online Education, and Active Learning Principles.
3	Course organization in the Virtual Learning Environment (VLE)
4	VLE tools for practical activities.
5	Curation and development of digital teaching materials.
6	Apps to enhance online classes.
7	Active learning strategies supported by digital technologies.
8	Assessment for Online Education

Upon completion of the training, it is expected that participating instructors will demonstrate the development of digital competencies, having experienced the learning process from the perspective of a student. Furthermore, the topics covered throughout the course will support the planning of lessons that incorporate diverse strategies aligned with the context of Online Education.

While the eight-session course equips participants with the essential knowledge, skills, and digital competencies required to design rigorous online and blended classes, sustained improvement in teaching practice depends on support structures that extend beyond the classroom. The next section, therefore, outlines a set of complementary faculty-development actions that deepen, disseminate, and institutionalise the impact of the training.

4 Complementary Faculty-Development Actions

In addition to a teacher training course for engineering professors, with an emphasis on active learning and the use of technological resources, the researchers who developed this course believe that it is essential to implement complementary actions that strengthen pedagogical practice and encourage critical reflection on engineering education. The following initiatives extend the impact of the core course and align with the theoretical framework outlined in Section 2:

- (i) Peer Mentoring: More experienced professors would accompany and guide colleagues at the beginning of their careers or in the process of methodological transition, that is, transitioning from so-called traditional teaching to constructivist teaching. This exchange between peers would favor continuous professional development and create a safe space for discussing planning that is more focused on active learning (Tillema, van der Westhuizen, & Smith, 2015).
- (ii) Reciprocal Classroom Observation: Another relevant initiative would be cross-observation of classes, in which professors would visit each other's classes to observe the methodologies used to develop classes, provide evidence-based feedback on learning task design, and reflect on good practices. This experience would promote self-reflection and collaborative learning, in addition to bringing the teaching community closer together (Saborido, Domínguez-Montes, Benjumea, & González-Calvo, 2024).
- (iii) Communities of Practice: The creation of communities of practice would also be strategic and especially relevant in the current context of implementing the new National Curricular Guidelines for undergraduate engineering programs in Brazil. In these communities, groups of professors, both from the same institution and different institutions, could meet periodically to share challenges, discuss solutions, analyze the results of pedagogical interventions, and collaboratively build knowledge about engineering education (Egwuonwu, Miller, Jensen, & Martin, 2022).
- (iv) Targeted Micro-workshops: Short-term thematic workshops focused on specific topics such as formative assessment, the use of data from assessment instruments to improve learning, the design of activities based on new active learning strategies, the role of artificial intelligence as a collaborator in teaching planning, and inclusive strategies for diverse learners. Each workshop culminates in an action plan reviewed by peers (Zenni, & Turner, 2021).
- (v) Scholarship of Teaching and Learning (SoTL): Engaging faculty in SoTL, for example, through action-research projects, strengthens the professional identity of the professors as reflective practitioners and nurtures a culture of pedagogical innovation in engineering education. Integrated into the proposed training course, these initiatives would expand their impact. Streveler, Borrego, and Smith (2007) note that SoTL typically starts with

an instructor's curiosity about student learning; its goal is to enhance learning by refining teaching, and its outcomes should enrich the literature on teaching and learning while contributing to faculty scholarship.

5 Final Considerations

The health emergency caused by the COVID-19 pandemic accelerated ongoing transformations in education, demanding the widespread adoption of digital technologies to ensure the continuity of teaching and learning processes. In this context, concepts such as Distance Education, Remote Teaching, Hybrid Learning, and Online Education became central to educational debates, demanding conceptual clarity and new pedagogical and digital competencies from educators. The training program presented in this text aims to address this challenge by offering engineering professors both theoretical and practical support for planning and mediating educational experiences. By engaging in active and interactive learning strategies, participants deepen their understanding of the role of instructional mediation in Online Education, strengthening their performance in both face-to-face and digitally mediated distance learning environments. In this way, the course contributes to a pedagogical practice that is more aligned with contemporary educational demands.

Although the course has already been offered experimentally several times, no systematic data collection has yet been undertaken. Consequently, this article focuses on documenting the instructional design rather than evaluating its effectiveness. The next step will be a mixed-methods study that will (i) administer pre- and post-course surveys to measure self-reported gains in digital-pedagogy competence, (ii) analyse artefacts produced during the sessions, and (iii) conduct semi-structured interviews to capture participants' perceptions and recommendations. The evidence gathered will guide iterative refinements of the materials and will be presented in a future publication.

Paraphrasing Weimer (1990), improving the quality of teaching and learning processes through faculty development is well worth the effort. The first to benefit from this process are the students. However, faculty members benefit themselves greatly as well. Teachers begin to experience the satisfaction of a job well done, which is significant, as few professions offer the profound personal fulfillment that teaching can provide. Higher education institutions also benefit once they gain credibility and prestige. Instructional excellence is just as difficult to cultivate as excellence in research, and institutions that achieve it deserve recognition.

Ultimately, although not always directly, society as a whole also benefits. When educators teach more effectively, grounded in constructivist principles, focused on the development of competencies, and supported by technologies and digital resources, they contribute to better student learning outcomes. In doing so, they help to shape professionals and global citizens who understand the world around them and their place within it, and who take an active role in their communities, working collaboratively to make our planet more peaceful, sustainable, and just.

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Digital Mobilizer App: An App to Introduce Basic Environmental Education and Motivate Population Engagement in Sustainable Development through Personas Created by Waste Pickers

João Mello da Silva¹, Márcia Longen Zindel², Simone Borges Simão Monteiro³, Antônio Augusto Maciel Guimarães⁴, Maria Fernanda Bastos Campani⁵, Frej Slot Arnfred⁶, Lutfur Rahman Rabbi⁷, Hristiyan Bozhilov⁸

¹ Graduate Program in Applied Computing, University of Brasília, UnB

^{2,3,4,5} Department of Production Engineering, University of Brasília, UnB

^{6,7} Techno-Anthropology, Aalborg University, AAU

⁸ International Human Research Management, Saxion University, Saxion

Email: joao.mellos@gmail.com, marcialz@unb.br, simoneborges@unb.br, antonio.guimaraes837@gmail.com, mariafe.bastos@gmail.com, farnfr23@student.aau.dk, arabbi22@student.aau.dk, 545699@student.saxion.nl

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Abstract

This paper presents the conception phase of the Digital Mobilizer App (DMA), an Information Module component of the Egalitarian project EcoLink project, part of the ERASMUS+ program funded by the EU. DMA aims to develop a mobile application to introduce basic environmental education and encourage engagement in sustainable development. The app features AI-generated personas created by waste pickers to represent themselves and their children, fostering inclusion and representation in educational initiatives. The paper consolidates the workshop results conducted during the Waste Summit Brasília 2025, involving ten CENTCOOP waste pickers, an entity representing over a dozen of waste picker cooperatives. The workshop, conducted by AAU, Saxion, and UnB students, supervised by UnB professors, utilized an AI-powered program from Educado, another Egalitarian project, to create personas based on participants' inputs. Waste pickers identified contamination as their main problem, alongside with hospital waste, low-quality recyclables, organic matter, and even animal corpses. They also highlighted the need for systemic improvements, including fines, external education, and awareness campaigns. The waste pickers suggested AI-generated child personas as influencers. The findings underscore strong participant engagement, with waste pickers expressing satisfaction with the personas, linking them to real individuals in their cooperatives. The study highlights the potential of AI-driven participatory design to empower marginalized communities, enhance their visibility, and support advocacy efforts. UnB's professors and students presented the results to another cooperative, which demonstrated strong interest in future workshops. The major reference for DMA during 2025 is the P3RD Model (P-Prevention, R₁-Reduction, R₂-Reuse, R₃-Recycling, D-Disposal), adaptation of the 10R Dutch Circular Economy Model. Within the scope of cooperatives of waste pickers, DMA will focus on Selective Collection, Triage/Sorting, Transformation, and Commercialization (C₁T₁T₂C₂), aligned with Reuse (R₂-Reuse) and Recycling (R₃-Recycling) components of the P3RD model.

Keywords: Digital Mobilizer; Personas Created by Waste pickers; Personas of Waste Pickers; Environmental Education; Population Engagement; Interest Groups; Waste Summit Brasília 2025.

1 Introduction

Environmental education plays a fundamental role in promoting sustainable development, especially when associated with initiatives that directly engage marginalized communities (Tilbury, 2011). The Digital Mobilizer App (DMA) emerges as an innovative tool within the EcoLink project, part of the Erasmus+ program funded by the European Union, aiming to foster environmental awareness and encourage community participation in sustainable practices (European Commission, 2020). DMA is aligned with all EcoLink's features: (i) a marketplace, connecting consumers to sustainable companies; (ii) an information hub, with educational content focused on sustainability; (iii) a reuse and recycling section, which facilitates donations and collections of reusable and recyclable materials; and (iv) a community space, dedicated to promoting interactions and events focused on sustainable practices. Thus, DMA plays a major role towards consolidating EcoLink as a tool for social

engagement and environmental awareness, offering an accessible and innovative resource that contributes to the adoption of more responsible habits, in addition to stimulating significant transformations towards a more conscious consumption model. By leveraging artificial intelligence (AI), the app allows waste pickers to create digital personas, enhancing inclusivity and social recognition in educational settings (Gunkel, 2020).

Regarding a major background, the Netherlands created a circular economy system with a vision extending up to 2050, structured around the R10 framework: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover Energy (Potting, J., et al., 2017).

DMA aims to explore the potential for adapting the Dutch R10 Model to create a version suitable for developing countries, specifically targeting contexts like Brazil and other developing countries. The project uses a modified model, named the P3RD Model: P= Prevention; R₁= Reduction; R₂= Reuse; R₃= Recycling; and D= Disposal. Besides considering that both, the Solid Waste Disposal into Biodigester Sanitary Landfills and the social-economical inclusion of the waste pickers now making a living in the existing open dumpsites, are relevant elements, this modification simplifies the original framework by focusing on five titles, rather than the ten utilized in the Dutch R10 Model. This adaptation seeks to establish circular economy project management guides tailored to the needs and capacities of developing nations. It is worthwhile to emphasize that all Rs of the Dutch R10 Model are included in the five titles of the P3RD Model: (i) Prevention and Reduction via Product Engineering (PR1) include Refuse, Rethink, Reduce; (ii) Reuse (R₂) encompasses Reuse, Repair, Refurbish, Remanufacture, Repurpose; (iii) Recycling (R₃) that includes only Recycling; and (iv) Disposal (D) into Biodigester Sanitary Landfills, built in such a way to avoid land contamination and allowing industrial use of the methane gas generated.

The DMA's application conceptualization phase was based on a workshop held during the Waste Summit Brasília 2025, which gathered ten waste pickers (seven women and three men) from CENTCOOP, an entity representing over a dozen of waste picker cooperatives (Dias, 2016). The workshop, conducted by researchers and students from UnB, Aalborg University, and Saxion University, provided valuable insights into key environmental challenges, such as waste contamination, hospital waste, poor-quality recyclables, organic waste mismanagement, and even animal carcasses in the recycling stream (Wilson et al., 2012). Furthermore, the waste pickers emphasized the need for systemic improvements, including fines, external education programs, and awareness campaigns (Gutberlet, 2015).

This study builds upon previous research that highlighted the importance of participatory design methods for ensuring the inclusion of marginalized waste pickers in system development (Rahman Rabbi et al., 2024). The Egalitarian Semester Project at AAU demonstrated that participatory methods such as design cards, personas, and scenarios can be successfully used to integrate waste pickers into digital platforms, fostering trust and transparency in waste management system. Inspired by this approach, the DMA project employs AI-generated personas to enhance waste pickers' representation in environmental education.

One of the major innovations of the project is the implementation of AI-generated child personas, suggested by the waste pickers themselves, as influencers in the dissemination of environmental knowledge (Kang et al., 2021). This participatory approach underscores AI's potential in empowering marginalized communities, amplifying their visibility, and supporting their role as key stakeholders in sustainability efforts (Scholz et al., 2018).

The DMA content development in the first semester of 2025 will be based on the Dutch 10R Circular Economy Model, adapted to the P3RD model (P-Prevention, R₁-Reduction, R₂-Reuse, R₃-Recycling, and D-Disposal) (Kirchherr et al., 2017). Within the waste picker cooperatives' context, the app will focus on Selective Collection, Triage/Sorting, Transformation, and Commercialization (C₁T₁T₂C₂), aligning with Reuse (R₂) and Recycling (R₃) principles (Ellen MacArthur Foundation, 2019).

This paper presents the DMA's conception phase, exploring workshop findings and discussing the potential of AI-driven participatory design to strengthen environmental education and enhance waste pickers' social engagement (Baldé et al., 2017).

2 Summary of the Digital Mobilizer App (DMA) Project

The Digital Mobilizer App (DMA) generator is an innovative digital tool designed to enhance environmental education and promote sustainable development through community engagement (Tilbury, 2011). Developed within the EcoLink project, the DMA generator leverages artificial intelligence (AI) to create digital personas, allowing waste pickers to represent themselves and communicate key environmental messages to a wider audience (European Commission, 2020).

The primary objective of the DMA is to educate, both the population in general and common interest groups, about waste management practices and circular economy principles while amplifying the voices of waste pickers (Wilson et al., 2012). The app integrates AI-generated personas developed in collaboration with waste pickers, ensuring a participatory approach that enhances social inclusion and knowledge dissemination (Gutberlet, 2015).

The key goals of the DMA application project include:

- Providing accessible environmental education through interactive digital content (Baldé et al., 2017),
- Encouraging behavioral change by engaging users with AI-driven storytelling techniques (Gunkel, 2020),
- Strengthening the role of waste pickers by using digital personas to share their expertise and lived experiences (Dias, 2016),
- Fostering community-driven solutions for sustainable waste management and circular economy adoption (Kirchherr et al., 2017).

The DMA app is specifically designed for implementation within waste picker cooperatives, focusing on $C_1T_1T_2C_2$, key elements of sustainable waste management (Ellen MacArthur Foundation, 2019).

The DMA is expected to contribute significantly to environmental education and digital inclusion, particularly among marginalized waste picker communities (Dias, 2016). By leveraging AI to facilitate participatory design, the project aims to:

- Empower waste pickers by giving them an active role in sustainability education (Wilson et al., 2012),
- Increase environmental awareness and responsible waste disposal habits among the population and common interest groups (Tilbury, 2011),
- Improve waste management efficiency through enhanced knowledge-sharing and community-driven solutions (Baldé et al., 2017),
- Support policy advocacy efforts by using AI-generated personas to highlight the challenges and contributions of waste pickers (Scholz et al., 2018).

The Digital Mobilizer App (DMA) is designed as a public-facing educational tool to enhance environmental awareness and promote sustainable development through waste separation. By integrating AI-generated personas created in collaboration with waste pickers, DMA aims to transfer the traditional role of street mobilizers into a dynamic digital platform. These personas, including adult and child representations, serve as relatable characters to guide users through interactive content on proper waste disposal practices, contamination risks, and circular economy principles. The app emphasizes inclusive representation, with waste pickers actively co-creating digital characters that reflect their realities and promote behavioral change among the general population.

At the current stage, the DMA remains in its preparatory and conceptual phase. The foundational design and persona development took place during a participatory workshop at the Waste Summit Brasília 2025, involving ten waste pickers from CENTCOOP. Full-scale development of the application is scheduled to begin in the second semester of 2025, led by students and researchers from UnB, AAU, and Saxion University. This upcoming phase will include prototype construction, user interface design, educational content creation, and pilot testing with diverse user groups to ensure impact, usability, and potential for policy advocacy.

3 The Workshop as the Starting Point of the MDA Project

DMA initial conceptualization resulted from a participatory workshop held during the Waste Summit Brasília 2025. The workshop was designed to engage waste pickers in both, identification and preliminary characterization of problems related to $C_1T_1T_2C_2$ and the development of AI-generated personas that accurately reflect their experiences and aspirations, ensuring inclusivity in environmental education (Gutberlet, 2015).

The methodology employed in the workshop followed a qualitative and participatory approach, where waste pickers were actively involved in discussions, persona creation, and problem identification related to their daily activities (Scholz et al., 2018). The process aimed to foster collaborative decision-making and co-design principles, reinforcing the idea that waste pickers should have agency over their representation in digital platforms (Dias, 2016).

3.1 Methodology

The workshop methodology was based on semi-structured interviews, focus groups, and interactive AI-based persona generation. The process unfolded in the following steps:

- Discussion on Representation: Waste pickers were encouraged to express how they wanted to be represented by AI, ensuring that digital personas reflected their identity, aspirations, and lived experiences (Gunkel, 2020),
- Persona Creation: AI technology from the Educado, another Egalitarian project was used to generate digital personas based on waste pickers' inputs. This participatory design approach enabled waste pickers to provide direct feedback on persona accuracy (Kang et al., 2021),
- Feedback and Adjustments: Participants evaluated the personas and provided suggestions for improvements, ensuring that the final representations were authentic and empowering (Scholz et al., 2018),
- Problem Identification and preliminary characterization: Participants highlighted the main challenges in waste collection, such as contamination, unsafe working conditions, and lack of public awareness (Wilson et al., 2012).

The workshop's methodology was designed to be iterative, meaning that personas could be refined and adjusted based on participant feedback over time (Gutberlet, 2015). It is worthwhile to emphasize that the problem Identification and preliminary characterization activities were performed during the time the AI program was generating the personas.

3.1.1 Role and Profile of the Participants

The workshop brought together waste pickers, supervising professors, and students from three universities, each contributing to different aspects of the research process.

3.1.1.1 Waste Pickers

A total of seven women and three men from the CENTCOOP network of waste picker cooperatives participated in the workshop. They were asked to provide insights on how they wanted to be represented by the AI program and responded to questions about their future goals and the main challenges of waste collection (Dias, 2016).

Their contributions were essential in shaping the personas, ensuring that the AI-generated characters reflected real-life experiences and addressed key issues within the waste management ecosystem (Wilson et al., 2012).

3.1.1.2 Supervising Professors

Professors from the University of Brasília (UnB) guided the students and assisted with translations. Their responsibilities included:

- Ensuring that the questions posed to waste pickers aligned with the project's research objectives (Tilbury, 2011),
- Helping to bridge the communication gap between international students and local waste pickers (Gutberlet, 2015),
- Providing academic oversight to ensure methodological rigor (Scholz et al., 2018).

3.1.1.3 Students

Students from Aalborg University (AAU) and Saxion University were responsible for conducting interviews with waste pickers, with the support of UnB professors for translation and methodological guidance. Their roles included:

- AAU and Saxion students: Conducted interviews and structured discussion sessions, ensuring that waste pickers' insights were fully explored (Dias, 2016),
- UnB students: Assisted in persona generation and translations, helping to adapt AI-generated characters to better reflect waste pickers' identities (Kang et al., 2021).

This collaborative approach ensured that all participants played an active role in the research process, leading to more accurate, inclusive, and community-driven outcomes (Gunkel, 2020).

4 Results

The participatory workshop conducted during the Waste Summit Brasília 2025 provided valuable insights into the perspectives, challenges, and aspirations of waste pickers. The findings from this engagement were critical in shaping the development of the Digital Mobilizer App (DMA) and reinforcing the importance of AI-generated personas as a tool for environmental education and social representation.

These insights were gathered through a combination of ethnographic methods, participatory design techniques, and direct input from waste pickers, including written reflections during the workshop. This section presents the main findings from the visit, discussing their implications for the project.

4.1 Key Findings from the Workshop

The results obtained during the workshop reinforced several key themes that are central to the design and implementation of the DMA project:

- Presence of hospital waste in recycling streams, which poses severe health risks,
- Low-quality recyclables, making the sorting process less efficient and reducing the economic value of collected materials,
- Organic waste improperly mixed with recyclables, complicating the sorting process and generating additional waste,
- Unexpected hazardous materials, such as animal carcasses, which create unsanitary working conditions.

These findings highlight the need for better segregation at the source, as well as public awareness campaigns to educate households and businesses on proper waste disposal practices.

4.2 Representation Through AI-Generated Personas

One of the most innovative outcomes of the workshop was the strong engagement with the AI-generated personas. Waste pickers enthusiastically interacted with the digital characters, providing constructive feedback and even naming the personas based on real people they knew. This response highlighted how realistic and relatable the AI-generated personas were, reinforcing their potential as engagement tools for environmental education.

A key takeaway from this process was that waste pickers wanted to see themselves accurately represented—not only in terms of physical appearance but also in personality and attitude. The reactions to each persona illustrate how AI-generated representations can be refined through participatory feedback, ensuring that they resonate with the intended audience.

4.2.1 First Persona – Older Man (Initial Version Perceived as Too Serious)

The first AI-generated image (Figure 1) presented an older man who was perceived as too serious by the waste pickers. While they appreciated the effort, they felt that the persona's facial expression and demeanor did not fully capture their reality. The initial representation seemed distant, prompting discussions about the importance of warmth and relatability in AI-generated characters.

4.2.2 Second Persona – Woman (Minor Adjustments Required)

The second image (Figure 2), depicting a middle-aged woman, was well received but required small adjustments to better align with the waste pickers' expectations. The group suggested minor refinements to facial features and expressions, emphasizing that the persona should appear approachable and familiar. After these modifications, the waste pickers felt the persona accurately reflected someone from their community.



Figure 1-First image of a man generated



Figure 2. First image of a woman generated

4.2.3 Third Persona – Refined Older Man, Named "Roberto"

Based on the feedback from the first image, a corrected version of the older man was generated. This time, the waste pickers responded positively, noting that the new persona closely resembled someone they knew. They affectionately named him Roberto (Figure 3), solidifying the persona's acceptance as a representation of their reality. This moment underscored how adjustments in AI-generated images can significantly impact how they are perceived.

4.2.4 Fourth Persona – Woman, Named "Dona Ana"

The fourth image featured a woman whom the waste pickers instantly related to. They enthusiastically named her "Dona Ana" (Figure 4), a title reflecting respect and familiarity. This strong connection demonstrated how

AI-generated personas, when done right, can evoke an emotional response and foster a sense of ownership and representation.

4.2.5 Fifth and Sixth Personas – AI-Generated Children, Named "Aninha" and "Robertinho"

A defining moment of the workshop was the creation of child personas, a suggestion of the waste pickers. They asked for two children, which were generated and named "Aninha" (Little Ana) and "Robertinho" (Little Roberto). The reaction was overwhelmingly positive and emotional—waste pickers compared these personas (Figures 5 & 6) to their own children, reinforcing the strong cultural and emotional significance of these representations.



Figure 3. "Roberto"



Figure 4. "Dona Ana"



Figure 5. "Aninha"



Figure 6. "Robertinho"

The waste pickers defended the idea of using child personas as AI-driven influencers, as they believe that child figures could be more effective in engaging the public regarding sustainability in family contexts as well as towards the engagement of other children. This aligns with the Egalitarian Semester Project at AAU findings, which showed that personas can serve as powerful advocacy tools for marginalized communities.

4.3 Need for Systemic Changes

The workshop also revealed the waste pickers' perspectives on systemic improvements, emphasizing the importance of:

- Stronger enforcement of fines for improper waste disposal,
- Educational initiatives targeting businesses and households to improve sorting practices,
- Advocacy for policy changes to recognize the role of waste pickers in formal waste management strategies.

These findings support the idea that the DMA project should not only serve as an educational tool but also as a mechanism for broader advocacy efforts to improve waste management policies.

4.4 Implications for the DMA Project

The results of the workshop have direct implications for the next phase of the DMA development:

- Content Development: The AI-generated personas should be designed to educate users about contamination issues and other best practices for waste sorting,
- Engagement Strategies: The use of child personas as influencers should be explored further, as suggested by the waste pickers,
- Policy Integration: The DMA should include educational content that advocates for policy changes, aligning with the systemic improvements proposed during the workshop.

These findings align with research on participatory waste management, reinforcing the importance of co-designing tools with waste pickers to enhance their visibility and social impact (Rahman Rabbi et al., 2024).

4.5 Preliminary validation of results

UnB professors and students went to another cooperative in Brasilia (Recicla Mais), where they presented the DMA's results (Figures 3 to 6) and ideas to a real-life mobilizer, a waste picker, and an administrative person. Besides suggesting some minor modifications on the personas generated at CENTCOOP, the three Recicla Mais people recognized DMA's potential to generate real and meaningful impact within their community and expressed strong interest in future DMA workshops related to content creation as well as the generation of new personas and the corresponding avatars.

5 Work to be Done by Students During the Year of 2025

During the first semester of 2025, students from UnB, Aalborg University (AAU), and Saxion University will collaborate to transform the DMA from a conceptual model into a functional prototype aimed at educating the population in general and interest groups, on waste management. While initially inspired by the experiences of waste pickers, the DMA is designed to be a public-facing platform, encouraging broader societal engagement with sustainability and circular economy principles. Additionally, the DMA will serve as a proof of concept to be presented to government authorities, with the objective of securing public incentives and policy support for improved waste management initiatives.

One of the primary tasks for the students will be refining the AI-generated personas, ensuring that they accurately represent the diversity of waste management stakeholders. The feedback from waste pickers during future workshops will be incorporated to enhance the realism and relatability of the personas, making them appealing and trustworthy for a broader audience. The characters, including "Roberto", "Dona Ana", "Aninha", and "Robertinho", will be fine-tuned to effectively communicate sustainability concepts and act as engaging digital guides within the app. Additionally, the AI speech synthesis system will be improved to create natural-sounding voices, enhancing the user experience and making the interaction more immersive.

Alongside persona refinement, students will work on developing the DMA framework, ensuring it is intuitive and engaging for the population. The platform will feature a user-friendly interface that allows individuals to explore different aspects of waste management, interact with AI-driven storytelling, and participate in gamified learning experiences. DMA will also incorporate interactive challenges, quizzes, and rewards to encourage users to actively engage with recycling, waste reduction, and proper disposal practices in their daily lives.

A major focus of the project will be creating compelling educational content that resonates with the broader population. Using AI-driven narratives, the app will present real-world waste management scenarios, showing how individual actions contribute to a more sustainable society. The learning modules will be structured according to internationally recognized sustainability frameworks, including the P3RD model (P-Prevention, R₁-Reduction, R₂-Reuse, R₃-Recycling, and D-Disposal), an adaptation of the 10R Dutch Circular Economy framework, ensuring that users receive accurate and impactful information. In addition, the app will feature personalized recommendations, allowing users to track their learning progress and receive actionable tips on how to improve their waste management habits.

To validate the effectiveness of the app and gather critical feedback, pilot testing will be conducted with a diverse group of users, including students, professionals, families, and environmental advocates. These test sessions will assess engagement levels, usability, and knowledge retention, ensuring that the platform effectively motivates behavioral change regarding waste disposal and recycling. The feedback collected will guide further refinements before wider public deployment.

Beyond the technical and educational aspects, students will also focus on leveraging the app as a tool for policy advocacy. The goal is to use the data and insights gathered from public interactions with the platform to

demonstrate its potential impact on waste management at a societal level. This information will be compiled into reports and presentations advocating for incentive programs and regulatory changes that support sustainable waste management practices.

By the end of the year, the objective is to have a DMA functional public prototype, equipped with engaging AI personas, interactive sustainability lessons, and a foundation for publicity and policy discussions.

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The use of Generative AI in Academic Work: Insights from University Students and Faculty

Sandra Fernandes^{1,2}, Alexandra M. Araújo^{1,3}, Pedro Rodrigues^{1,3}, Sara Fernandes^{1,3}

¹Department of Psychology and Education, Portucalense University, Porto, Portugal

²CIEC - Research Centre on Child Studies, University of Minho, Braga, Portugal

³CINTESIS.UPT@RISE-Health, Portucalense University, Porto, Portugal

Email: sandraf@upt.pt, amaraujo@upt.pt, prodriques@upt.pt, sarab@upt.pt

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Abstract

The integration of generative Artificial Intelligence (AI) in higher education raises several discussions on its ethical use, academic integrity, and its role in learning. This study explores the perceptions of students and faculty regarding the use of generative AI in academic assignments, focusing on ethical considerations, student learning, and institutional guidelines. A survey was conducted among undergraduate and graduate students (N=329) and faculty members (N=14) belonging to a specific department (not in the field of STEAM) of a private higher education institution in Portugal. The survey comprised three sections: (I) Use of generative AI in academic contexts, (II) Perceptions of ethical generative AI use, and (III) Practical application of generative AI in academic assignments. Data analysis involved descriptive statistics to identify agreement trends and differences between students and faculty perceptions. Findings reveal significant differences in perceptions. While most respondents acknowledge generative AI as a valuable support for learning, opinions diverge on its impact on skill development and the ethical implications of its use in assessments. Approximately half of both groups disagree on whether GAI negatively affects students' competencies. Despite these variations, there is a strong consensus on the need for clear institutional guidelines to regulate AI's role in academic work. This research highlights the need for improved digital literacy and ethical awareness among both students and faculty. It also underscores the importance of establishing structured discussions and collaborative frameworks to navigate the responsible use of AI in education. The findings contribute to ongoing debates on AI adoption in academia and call for the development of best practices to ensure ethical and effective AI integration in learning environments.

Keywords: Generative AI, Higher Education, Academic Integrity, Ethical AI Use

1 Introduction

The integration of generative Artificial Intelligence (AI) in higher education raises several discussions on its ethical use, academic integrity, and its role in learning (Chiu, 2024; European Commission: Directorate-General for Education, 2022; Nguyen et al., 2023; Vodafone Foundation, 2025).

Although AI presents many advantages, its implementation must be guided by ethical principles to address potential challenges, particularly in relation to student learning and assessment practices (Cotton et al., 2024; Eke, 2023; Lo, 2023; Waltzer, Cox, et al., 2023). The European Commission (2022) highlights the importance of educators engaging critically with AI technologies to ensure these systems remain transparent, trustworthy, and equitable within educational environments. Traditional assessment methods—primarily relying on written exams and essays—should be reimagined to prioritize authentic assessment tasks. These tasks aim to evaluate students' abilities to apply and integrate competencies in real-world contexts, fostering dialogue and reflection between students and educators (Mai et al., 2024; Waltzer, Cox, et al., 2023; Waltzer, DeBernardi, et al., 2023; Waltzer et al., 2024).

Recent studies show varying opinions among university faculty regarding the integration of generative AI in higher education. While many teachers acknowledge the educational potential of AI tools like ChatGPT, their adoption is hindered by concerns about academic integrity, the erosion of critical thinking skills in students, and the need for adequate training and institutional guidelines (Cabellos et al., 2024; Kiryakova & Angelova,

2023). Students also seem to have a generally positive, yet nuanced view of AI tools in the learning process, as they appreciate these tools for their efficiency and ability to provide instant feedback, clarify complex concepts, and support independent learning, but remain concerned about a potential overreliance on these tools and what constitutes ethical usage (Cavazos et al., 2024; Johnston et al. 2024). Students' attitudes towards AI showcase uncertainty, with some adopting a pragmatic approach to its use to strategically navigate academic pressures, while others remain hesitant due to unclear institutional policies and personal concerns about authenticity (Stone, 2024).

The current study further explores the perceptions of students and faculty regarding the use of generative AI in academic assignments, focusing on ethical considerations, student learning, and institutional guidelines. Data was collected after the implementation of general guidelines for the integration of AI into academic practices at a Portuguese university, described as followed.

2 Roadmap of the integration of Generative AI in Higher Education

The integration of generative AI into academic environments requires intentional planning, clear communication, and structured implementation. In the context of a Portuguese higher education institution (HEI) in which students' and faculty's data was collected, the adopted approach can be explained by the roadmap presented on figure 1, which outlines a strategic, phased approach to incorporating AI in the educational framework of the HEI.

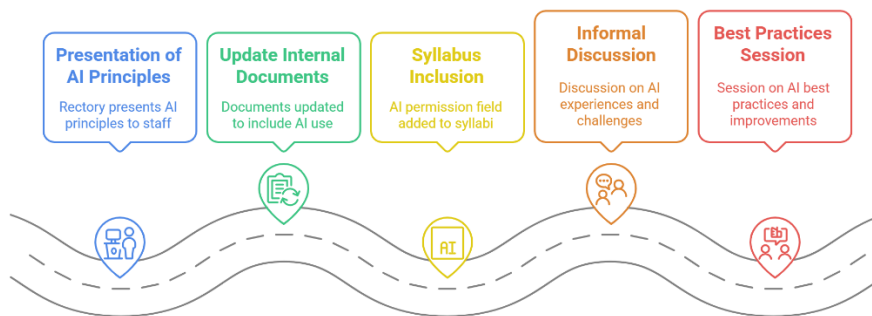


Figure 1. Roadmap of the implementation of Generative AI at the Higher Education Institution

This model reflects a commitment not only to digital innovation in the teaching and learning process, but also to transparency, collaboration, and continuous improvement. The roadmap of the integration of Generative AI in this specific HEI can be explained in five key stages:

1. Presentation of AI Principles - The process began with an introductory presentation, led by the Rectorate, about the AI principles to the academic staff. This presentation served to establish a shared understanding of the ethical, pedagogical, and operational dimensions of generative AI use in education. It aimed to set the alignment regarding the institutional values and guidelines that will guide AI integration across courses and disciplines.

2. Development of Internal Documents - Following the initial presentation, specific documents were created (for example, the "Declaration for the Use of Generative AI for Academic Work" – see figure 2) and internal academic documents (Pedagogic Regulation, Course Syllabus, etc.) were reviewed and updated to explicitly include reference to the use of generative AI. This step aimed to assure that institutional policies also reflected the incorporation of AI tools in the academic practices.

STUDENT IDENTIFICATION Name of Student 1 (number XXXXX), Name of Student 2 (number YYYYY), ...
ARTIFICIAL INTELLIGENCE USAGE STATEMENT In this work <u>we used/did not use</u> Generative Artificial Intelligence (AI) systems to <u>improve the language/structure of the text, and/or search for information and/or <indicate if other use></u>. The Generative AI system(s) used in this work was the following: <u>ChatGPT/ Gemini/ Copilot/ ...</u>
SCOPE OF USE If Generative AI was used, briefly <u>describe, and justify, for what purpose</u> generative AI was used in the context of the academic work.
PROMPTS USED If Generative AI has been used, <u>identify here the prompts that have been used.</u>

Figure 2. Declaration of the use of Generative AI for Academic Work

3. Syllabus Inclusion - To embed the use of AI at the course level, a specific field for AI permissions and guidelines was added to all syllabi (see Figure 3). This change aimed to promote transparency between teachers and students regarding acceptable AI usage in assignments and assessments. It also encouraged the development of course-specific policies that consider the unique learning objectives and disciplinary norms of each program.

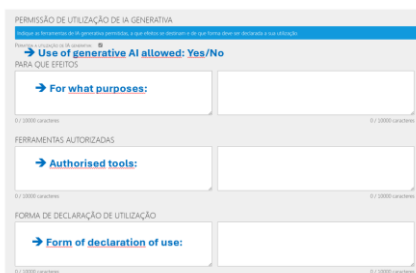


Figure 3. Inclusion of a new field in the course syllabus: Generative AI Permission

4. Informal Follow-up Discussions - Recognizing the importance of reflective practice, after the start of the first semester of 2024/2025, the Rectory and the Pedagogic Innovation Office, organized informal discussions among faculty and students to obtain feedback about the preliminary results of the integration of generative AI in the curricular units. These sessions provided a space to share experiences, discuss challenges, and explore innovative uses of AI in the classroom, among the different departments of the university. This collaborative approach intended to foster a culture of peer learning among faculty.

5. Best Practices Session – At the end of the first semester, a session dedicated to sharing best practices allowed for the dissemination of successful strategies and the identification of areas for improvement. This session helped create a cycle of feedback, where teachers shared how they used generative AI in the classroom, and these experiences were used to improve teaching practices for the second semester of 2024/2025.

In sum, by gradually involving all stakeholders and embedding AI considerations into institutional documents, curriculum design, and teaching practice, this HEI aimed to create a responsible, effective, and innovative learning environment.

3 Methods

This study explores the perceptions of students and faculty regarding the use of generative AI in academic assignments, focusing on ethical considerations, student learning, and institutional guidelines, following the implementation of the previously described roadmap for the integration of generative AI in teaching and learning.

The objectives of the study include the following:

- To understand the perception of students and teachers regarding the use of generative AI in students' academic work;
- To identify relevant aspects that deserve greater attention and reflection, comparing the results of the students with those of the teachers;
- To reflect on specific training needs regarding the use of generative AI for students and teachers.

A survey was conducted among undergraduate and graduate students of a specific department from a Portuguese university. It was organized in three sections: (I) Use of generative AI in academic contexts, particularly in students' academic assignments (II) Perceptions of ethical use of generative AI, and (III) Practical application of generative AI in academic assignments. Data analysis involved descriptive statistics to identify agreement trends and differences between students and faculty perceptions.

4 Results

In this section, results will be presented according to students' and teachers' perceptions about the use of generative AI in academic assignments. In this paper, we only highlighted some results.

4.1 Students' Perceptions about the use of Generative AI in Academic Work

In general, the analysis of results from the survey to students reveals that students have a range of mixed opinions about using generative AI in academic settings.

From the analysis of Table 1, it is possible to conclude that student's responses indicate a divided perspective on whether the use of generative AI compromises the originality of academic work, with approximately one-third agreeing with the statement (30%), one-third disagreeing (36%), and the remaining participants expressing neutrality (34%). A significant proportion of students (72%) expressed a favourable opinion on the use of generative AI for any academic purpose, as long as its use is transparently declared. In contrast, only 24% of students agreed that AI negatively affects the development of academic skills, while 48% disagreed with this claim. There was strong consensus among students on the necessity for institutional regulation, with 84% agreeing that universities should establish clear guidelines on the ethical use of AI. Similarly, 88% agreed that lecturers should explicitly communicate what constitutes acceptable AI use within different types of assessment. Students also demonstrated a highly positive stance on the responsible integration of AI into the learning process. The majority (93%) agreed that AI tools should serve as a support mechanism for learning, rather than as substitutes for academic effort. Moreover, 81% considered it ethically acceptable to use AI for generating creative or innovative ideas, as long as the student made a meaningful contribution to their development. When confronted with uncertainty about the ethical use of AI, 89% of students indicated that they would consult their lecturers. However, there was less agreement regarding the proposition that AI should be limited in assessed work to ensure that outcomes reflect students' own efforts, with only 35% in agreement and a similarly large proportion expressing disagreement (33%) or neutrality (32%). Finally, 77% agreed that AI use should be viewed as ethical only when it does not compromise the primary objectives of academic assessments, such as evaluating students' knowledge and competencies.

Table 1. Results from the Survey to Students

Items	% Agree	% Neither Agree nor Disagree	% Disagree
1. The use of generative AI compromises the originality of academic work.	30%	34%	36%
2. Students may use generative AI for any purpose, as long as they declare its use.	72%	13%	15%
3. Generative AI has a negative impact on the development of students' skills.	24%	28%	48%
4. The University should establish clear guidelines on the use of generative AI in academic work.	84%	12%	5%
5. Lecturers should clearly explain to students what is considered an ethical use of AI in each type of assessment.	88%	10%	2%
6. Generative AI tools should be seen as support for learning, but not as a substitute for academic effort.	93%	6%	1%
7. The use of generative AI to simulate creative or innovative ideas in a work is ethical, as long as the student contributes to the development of those ideas.	81%	14%	5%
8. When in doubt about the ethical use of AI, students should consult their lecturers before using these tools.	89%	9%	2%
9. It is more ethical to limit the use of AI in assessed work, so that the result directly reflects the student's effort.	35%	32%	33%
10. The use of AI is ethical only if its use does not compromise the main objectives of the assessment, such as assessing the student's knowledge and skills.	77%	18%	5%

4.2 Teachers' Perceptions about the use of Generative AI in Academic Work

Among teachers, perceptions largely converged with those of students on several issues, although key divergences were observed. As shown in Table 2, teachers were equally divided on the issue of whether AI compromises the originality of academic work (43% agreement and 43% disagreement), reflecting the same ambivalence seen among students. However, only 43% of teachers agreed that students should be permitted to use AI for any purpose provided its use is declared. Regarding the impact of AI on students' skill development, teachers again displayed polarized views, with 43% agreeing and 43% disagreeing with the notion that AI use hinders skill acquisition. This distribution suggests ongoing debate within the academic community about the pedagogical implications of generative AI. Teachers expressed even stronger consensus than students on the need for institutional regulation. Nearly all respondents (93%) supported the implementation of university-level guidelines, and 100% agreed that lecturers should communicate clearly with students regarding the ethical use of AI in assessments. Teachers also agreed (100%) that AI should serve as a supplementary tool for learning and not as a replacement for student effort, reinforcing a shared pedagogical stance with students. Regarding creative use of AI, 93% of teachers agreed that employing AI to simulate innovative ideas is ethically acceptable when students are active contributors. Teachers similarly agreed that students should consult instructors when uncertain about AI usage (100% agreement). Nonetheless, a greater proportion of teachers (57%) supported limiting AI in assessed work to ensure authentic student output, contrasting with students' relatively low agreement on this point (35%). Finally, a substantial majority of teachers (86%) recognized that ethical AI use must align with the core goals of academic assessments.

Table 2. Results from the Survey to Teachers'

Items	% Agree	% Neither Agree nor Disagree	% Disagree
1. The use of generative AI compromises the originality of academic work.	43%	14%	43%
2. Students may use generative AI for any purpose, as long as they declare its use.	43%	14%	15%
3. Generative AI has a negative impact on the development of students' skills.	43%	14%	43%
4. The University should establish clear guidelines on the use of generative AI in academic work.	93%	7%	-
5. Lecturers should clearly explain to students what is considered an ethical use of AI in each type of assessment.	100%	-	-
6. Generative AI tools should be seen as support for learning, but not as a substitute for academic effort.	100%	-	-
7. The use of generative AI to simulate creative or innovative ideas in a work is ethical, as long as the student contributes to the development of those ideas.	93%	7%	-
8. When in doubt about the ethical use of AI, students should consult their lecturers before using these tools.	100%	-	-
9. It is more ethical to limit the use of AI in assessed work, so that the result directly reflects the student's effort.	57%	-	43%
10. The use of AI is ethical only if its use does not compromise the main objectives of the assessment, such as assessing the student's knowledge and skills.	86%	7%	7%

5 Discussion

The current study aimed to explore perceptions of university students and teachers about the use of generative AI in academic assignments, focusing on ethical considerations, student learning, and institutional guidelines. Students and teachers reported their perceptions and attitudes towards the use of generative AI tools in academic assignments, following the described roadmap for the integration of generative AI in teaching and learning at a Portuguese university. Although most participants recognized generative AI as a beneficial aid in the learning process, their perspectives diverge on its influence on skills development and the ethical considerations. Approximately half of the participants in both groups disagree on whether Generative AI adversely impacts students' competencies. Divergent views also arise concerning acceptable applications, such as utilizing AI to draft introductions and conclusions or to compensate for the absence of group members. Nonetheless, there is a strong consensus between students and faculty on the urgency for institutions to establish clear and comprehensive guidelines to govern the role of AI in academic contexts.

These results are in line with recent studies. For instance, a study with Australian students revealed that, more than a third of students have used chatbots for assessment assistance, but do not necessarily perceive it as a breach of academic integrity (Gruenhagen et al., 2024). Approximately half of the participants in both assessed groups disagree on whether Generative AI adversely impacts students' competencies. Divergent views also arise concerning acceptable applications, such as utilizing AI to draft introductions and conclusions or to compensate for the absence of group members. A recent systematic review indicates that teaching academics acknowledge the potential of AI to enhance teaching efficiency and improve instructional practices, while emphasizing the importance of thorough training and well-defined policies for the effective and ethical integration of generative AI in higher education (Nikolic et al., 2024).

While Generative AI supports personalized learning experiences and fosters increased student engagement, it simultaneously raises critical issues related to the integrity of assessments, data privacy, and broader ethical considerations (Ahmed et al., 2024). Supporting prior research conclusions, this study's findings highlight the ambivalence among faculty and students, who are both intrigued by and cautious about the educational implications of using AI technologies to teach and learn (Cabellos et al., 2024; Kiryakova & Angelova, 2023). Both students and teachers value generative AI tools as important to support students' academic work and learning but are concerned about a potential negative impact on students' academic skills (Cavazos et al., 2024; Johnston et al. 2024).

The current study suggested that students and faculty need comprehensive guidelines to govern the role of AI in academic work. In the current study, students and teachers echoed a sense of ambiguity surrounding academic integrity guidelines. In accordance with prior research (Johnston et al., 2024; Stone, 2024), this study's findings emphasize the urgent need for higher education institutions to develop clear and ethical frameworks, along with support structures that guide both faculty and students in the responsible and effective use of generative AI technologies.

Finally, it is important to highlight that the present study is only descriptive and was composed by unbalanced groups of respondents, with a much higher participation of students compared to teachers. Results could have been influenced by lack of sufficient experience in the use of generative IA tools and social desirability. Despite being an exploratory and descriptive study with some limitations, the results show that there is a need for wider reflection on the use of Gen IA tools in academic contexts.

6 Conclusion

The current study presents results that can help HEI think about key questions in which students and faculty members present divergent opinions. The findings point to several critical areas that demand deeper reflection. First, the inconsistency shared by both students and teachers regarding the impact of AI on originality and skill development highlights the need for more evidence-based discussions within academic institutions. While both groups acknowledge the potential for AI to support learning, uncertainty persists regarding its long-term influence on student competencies and the authenticity of academic outputs. Addressing this ambiguity may require longitudinal research and pedagogical experimentation aimed at integrating AI in ways that enhance, rather than erode, core educational objectives. Second, the strong evidence from both groups for clear institutional guidelines underscores an urgent need for universities to establish comprehensive policies that articulate acceptable practices, ethical boundaries, and consequences of misuse. These policies should be co-developed with input from both faculty and students to ensure they are contextually relevant and practically applicable. A balanced approach and flexible guidelines can help integrate generative AI into university teaching and learning processes, benefiting both faculty and students (Cacho, 2024; Nguyen et al., 2023). Third, the differing perceptions surrounding the sufficiency of declaring AI use suggest a broader discussion regarding academic integrity. While students may perceive disclosure as a means of legitimizing AI-assisted work, educators appear to demand more rigorous standards, emphasizing the importance of individual authorship and learning outcomes. Bridging this gap may involve the development of discipline-specific frameworks that define the permissible scope of AI use within different types of assessments. In sum, the integration of generative AI into academic contexts is reshaping conceptions of authorship, learning, and assessment. While both students and teachers recognize the potential of AI as a learning support, careful consideration must be given to the development of ethical, pedagogical, and institutional frameworks that safeguard academic standards and support meaningful student engagement.

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Promoting Pedagogical Innovation for Student Success in Higher Education: Evaluating the Impact of Faculty Training at UPT

Sandra Fernandes¹, Alexandra M. Araújo^{1,2}, Elizabeth Real³

¹Department of Psychology and Education, Portucalense University, Porto, Portugal

²CINTESIS.UPT@RISE-Health, Portucalense University, Porto, Portugal

³Department of Economics and Management, Portucalense University, Porto, Portugal

Email: sandraf@upt.pt, amaraujo@upt.pt, elizabeth.real@upt.pt

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Abstract

Pedagogical innovation is key to improving teaching and learning in higher education. As part of the +Sucesso@UPortucalense project—funded by DGES and the PRR—a teacher training program was implemented at Portucalense University (2024–2026) to support academic success and reduce student dropout. One of the components of the program was teacher training in pedagogic innovation. Therefore, a training program was developed including five training courses focused on active learning methods: Project-Based Learning, Gamification, Assessment and Feedback, Online Learning, and Curriculum Planning. Faculty participated in hands-on sessions aimed at developing innovative teaching practices. Their satisfaction was assessed at the end of each training, through online surveys combining quantitative and qualitative data. Results showed positive satisfaction in using active learning strategies. The initiative proved effective in supporting faculty development and enhancing student engagement through innovative pedagogy.

Keywords: Pedagogical Innovation, Active Learning, Pedagogic Training, Higher Education, Student Success

1 Introduction

Pedagogical innovation plays a crucial role in enhancing the quality of teaching and learning in higher education. Current research highlights that innovative teaching practices—such as flipped classrooms, problem-based learning, and blended learning—significantly increase student engagement, motivation, and critical thinking skills (Alves & Fernandes, 2021; Bhuttah et al., 2024; Kaynardağ, 2017). These methods promote deeper learning by encouraging active participation and reflective thinking, shifting the focus from traditional, teacher-centered instruction to more dynamic, student-centered learning environments (Bonwell & Eison, 1991; Prince, 2004).

To effectively implement these innovative strategies, comprehensive pedagogical training for faculty members is essential. Pedagogic training provides the opportunity for faculty to engage with the tools necessary to create more motivating and effective learning environments. This training equips educators with the skills needed to integrate technology effectively and design inclusive, student-centered curricula (Muammar & Alkathiri, 2021; Stentiford & Koutsouris, 2020). When faculty members are proficient in innovative teaching methods and supported by inclusive leadership, students' critical thinking abilities and overall academic performance improve (Fernandes et al., 2023).

Moreover, pedagogical innovation helps create more motivating and effective learning environments. By adopting active learning methodologies and utilizing technological advancements, educators can develop flexible and engaging classrooms that accommodate diverse learning needs (Ödalen et al., 2018; Stentiford & Koutsouris, 2020). This adaptability not only enhances student academic success and satisfaction but also prepares learners to meet the evolving demands of the modern workforce (World Economic Forum, 2025).

This is one of the main goals of the +Sucesso@UPortucalense project, an institutional project implemented at Portucalense University, Porto, Portugal within the sub-measure of the “Program for Promoting Success and Reducing Dropout in Higher Education”, funded by the General Directorate for Higher Education (DGES) and the Recovery and Resilience Plan (PRR). The main objective of this program is to develop initiatives to promote academic success and prevent retention and dropout of first year students, including the development of innovative teaching and learning practices. The project has the duration of two years (2024-2026). Within the scope of this project, a teacher training program was developed and implemented in the academic year of 2024/2025, under the coordination of the Pedagogic Innovation Office at Portucalense University. The training focused on active learning methodologies and aimed to develop innovative teaching competencies among of faculty members. The five courses covered were: 1) Team-based learning – TBL (4h); 2) Project-based Learning – PBL (4h); 3) Gamification in the Classroom (5h); 4) Assessment and Feedback in Active Methodologies (6h); and 5) Design, Facilitation, and Assessment of Online Learning (20h). By exploring active learning principles, teachers reflected about their teaching strategies to better engage students and enhance academic outcomes.

2 Methods

The main objective of this paper is to present the results of the evaluation of teachers’ satisfaction with the pedagogical training courses carried out during the academic year of 2024/2025. The following research questions were defined to guide the study:

- To what extent are teachers at Portucalense University satisfied with the pedagogical training courses conducted during the academic year 2024/2025?
- What are the most positive and least positive aspects of the pedagogical training courses as perceived by the participating teachers?
- How do teachers plan to apply the knowledge and skills gained from the training sessions to their teaching practices within their curricular units?

Portucalense University is a private higher education institution located in Porto, Portugal. The teaching staff is distributed across six Departments: Architecture and Multimedia Gallaecia; Law; Psychology and Education; Economics and Management; Science and Technology; and Tourism, Heritage and Culture. It offers 15 different bachelor degrees, 19 masters and 3 PhD degrees. In terms of teachers and staff, it has about 250 professionals and more than 4100 students enrolled in the university programmes.

A mixed-methods approach was used, combining quantitative and qualitative data using online surveys at the end of each training course. The survey was applied at the end of the training sessions, with the aim of evaluating the satisfaction of the participants in regard to each of the five training courses. The questionnaire was created through the *Google Forms* tool. The structure of the questionnaire is presented in Table 1.

Table 1. Items in the Online Survey

Items	Type of Questions
1. The training session met my expectations.	Closed Response (Likert scale, 1 to 5)
2. The topics addressed in the training session were relevant.	
3. The training strategy used was adequate.	
4. I actively participated in the training activities.	
5. The trainer motivated the participants.	
8. In general, indicate your degree of satisfaction with the training session.	Open Response
6. What are the most positive and less positive aspects?	
7. How do you plan to transfer the knowledge and skills developed to your curricular units?	
Observations/Comments	

3 Results

In this section, the results from the five training courses are presented and discussed based on the quantitative data analyses, complemented with the qualitative findings from the open-ended questions. Table 2 presents the number of participants in the training courses and respondents.

Table 2. Participants in the Training Courses

Training courses	Nº. participants	Nº. responses to survey
Team-Based Learning (TBL)	13	6
Project-Based Learning (PBL)	21	7
Gamification in the Classroom	39	10
Assessment and Feedback in Active Learning	24	5
Design, Facilitation and Assessment of Online Learning	32	17

3.1 Team-Based Learning - TBL (3h)

The results suggest a high level of satisfaction with the training sessions, particularly in terms of content relevance, trainer effectiveness, and participant engagement. There is a slight variation, with participants scoring the general satisfaction and training strategy just below the perfect mark, indicating room for minor improvements, though overall satisfaction remains very high.

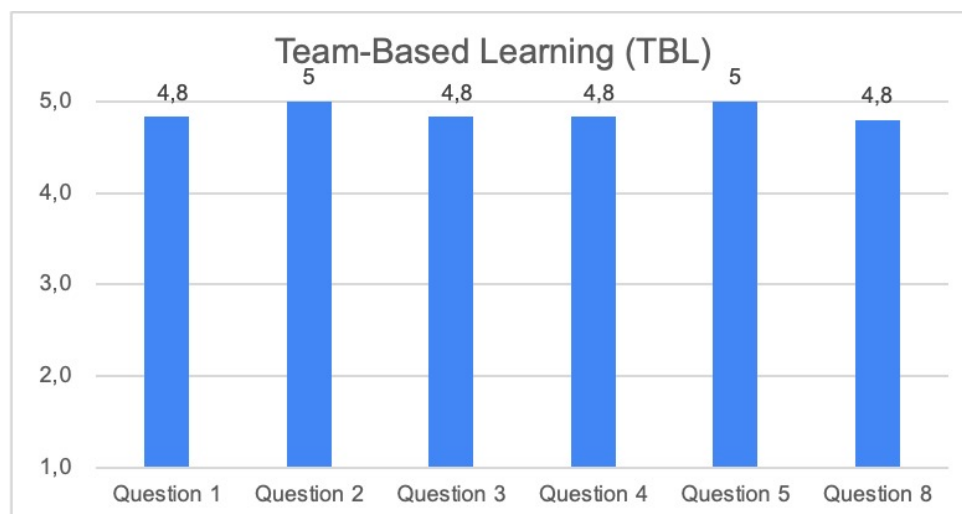


Figure 1. Results from participants in the training session "Team-based learning"

In the open ended-questions, the participants expressed the intention to apply the knowledge and skills gained in their teaching practices in practical applications in the classroom, enhancing student collaboration, improving lesson planning and facilitating theoretical content understating. Overall, the knowledge gained from the training will be applied to improve teaching strategies, foster collaboration, and enhance student learning outcomes through active participation and practical application of TBL. Some of the participants quotes confirm this:

"Apply TBL directly in the classroom context through practical activities."

"For more demanding courses, use TBL to motivate students and encourage team learning, fostering healthy competition."

"Adjust and improve the planning of future lessons using the methods learned."

3.2 Project-Based Learning - PBL (4h)

The results reflect generally positive feedback, particularly in terms of the trainer's ability to motivate participants and the relevance of the topics covered. However, there are areas, such as the adequacy of the training strategy and the level of active participation, where improvements could be made. The overall satisfaction is still strong, but there is room to further align the training strategy and increase engagement during the sessions.

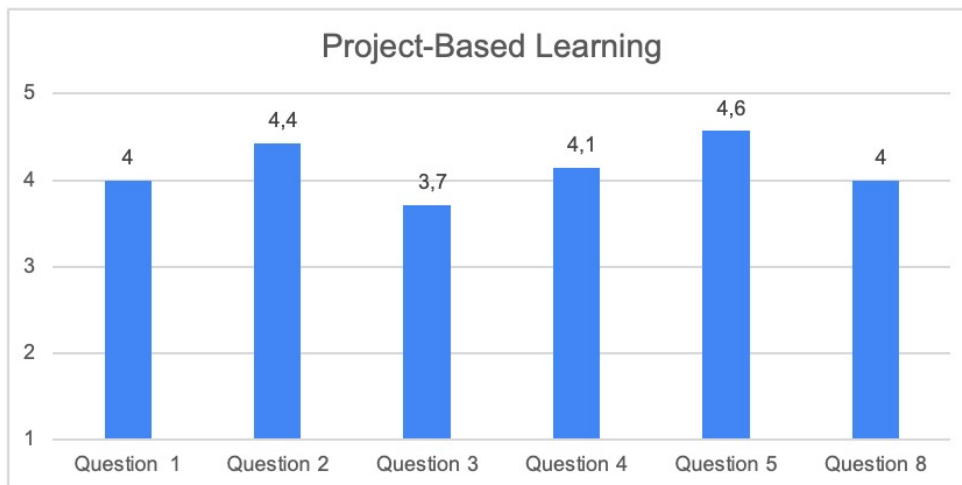


Figure 2. Results from participants in the training session "Project-based learning"

Participants plan to transfer the knowledge gained into their teaching environments, particularly through the implementation of projects, application of group management techniques, and adaptation of methods for the curricular unit. However, there is a perception that more time would have been necessary to explore all concepts and techniques in greater depth, with suggestions for adjustments to the format and the trainer's approach to enrich the learning experience. The following quotes from participants confirm this:

Strengths: Getting a good connection with the trainees. Improvement points: More time was needed to develop some aspects.

Strengths: the skills-based approach and the realization of the project as a team; Less strong points: in some situations, exposure could be reduced allowing more time to "do", more application.

3.3 Gamification in the Classroom (5h)

The "Gamification in the Classroom" training session received generally positive feedback, particularly in terms of the relevance of the topics and the motivation provided by the trainer. However, the training strategy could

benefit from refinement, as indicated by the relatively lower score of 3.8. While participants were actively engaged and satisfied with the session overall, there is room to enhance both the interactivity of the activities and the alignment of the training methods with the participants' needs to improve the experience further.

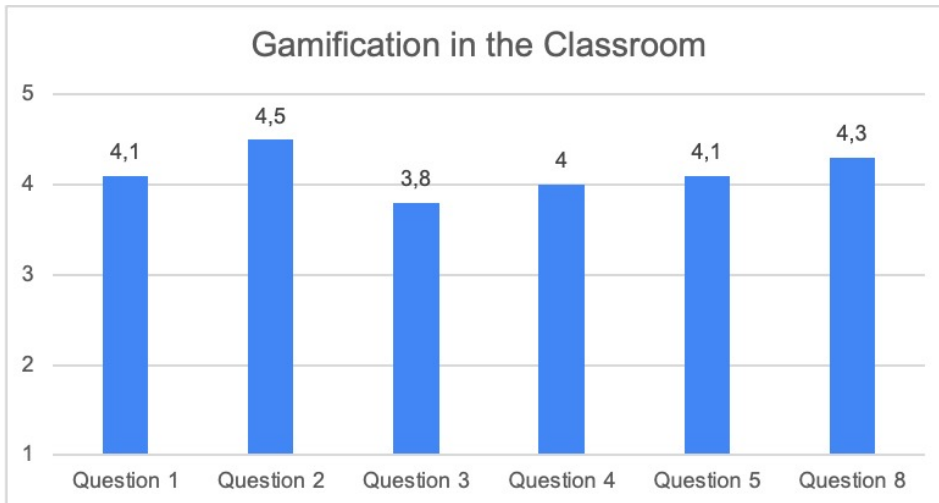


Figure 3. Results from participants in the training session "Gamification in the Classroom"

In the open-ended questions, participants indicated that the main strengths of the training were its innovative and relevant topic, practical examples of tools, the engaging approach of the trainer, and the availability of resources for adaptation to the participants' teaching needs. Several participants expressed an interest in applying the escape room method in their classrooms, with plans to implement it at the end of each topic or within specific curricular units. This will provide an engaging way to reinforce learning. The following quotes confirm this:

Very interesting and innovative topic for preparing some challenges in the classroom.

Strong points: Current and relevant topic. Knowing practical examples of tools we can use.

Continue to develop gamification-based activities in curricular units where students show greater resistance (e.g., Statistics). [I already use these strategies].

At the end of each topic, I would like to implement an escape room."

3.4 Assessment and Feedback in Active Learning (6h)

The "Assessment and Feedback in Active Learning" training session received strong feedback, particularly in terms of the trainer's effectiveness and the relevance of the topics covered. The high participation score also indicates that the session was interactive and engaging. While the overall satisfaction was positive, some minor improvements could be made in refining the training strategy and ensuring the session fully aligns with participants' expectations. Nonetheless, the session appears to have been a success, with room for slight enhancements to further elevate the experience.

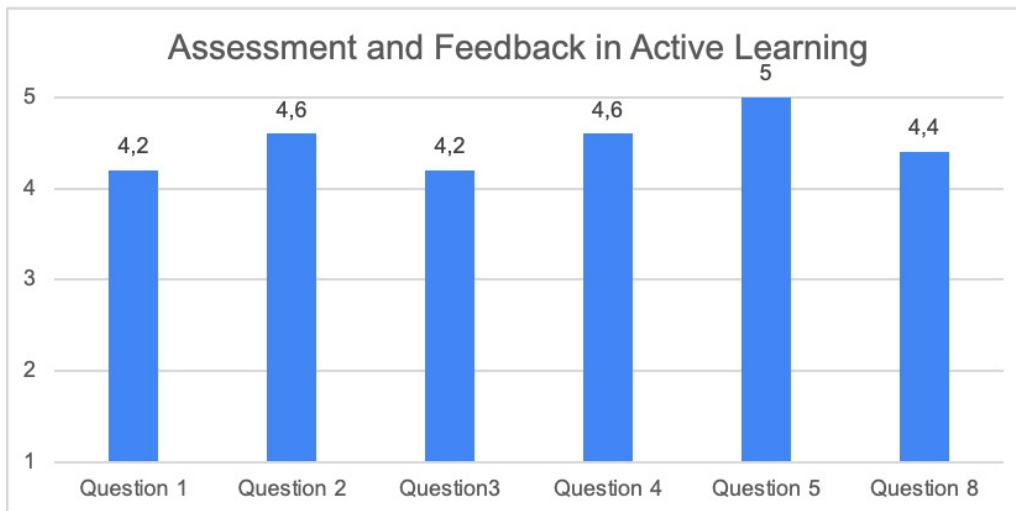


Figure 4. Results from participants in the training session "Assessment and Feedback in Active Learning"

Findings from the qualitative data indicate that the training's main strengths included the focus on competency-based assessment, the practical examples of assessment rubrics, and the clear and interactive teaching approach. Participants plan to revise their curricular units, focusing on competencies and evaluation methods, and will apply these strategies to improve their evaluation grids and teaching methods, ensuring that the learning and assessment process is more effective and transparent. The following quotes from participants confirm this:

Strong points: the approach to assessment with a focus on competencies and the exemplification of assessment rubrics.

I will redo the FUC of the course I will teach in the second semester, focusing on competencies and their assessment, using rubrics.

Improve the evaluation grid for interdisciplinary projects.

3.5 Design, Facilitation and Assessment of Online Learning (20h)

The "Design, Facilitation, and Assessment of Online Learning" training session was well-received, particularly in terms of the relevance of the content, the trainer's ability to motivate participants, and overall satisfaction. While most participants were actively engaged, there is room to improve the interactivity of the training activities and the alignment of the training strategy with participants' learning preferences. The high relevance of the topics indicates that the session addressed important issues, but there may be opportunities to enhance the delivery to increase both participation and engagement.

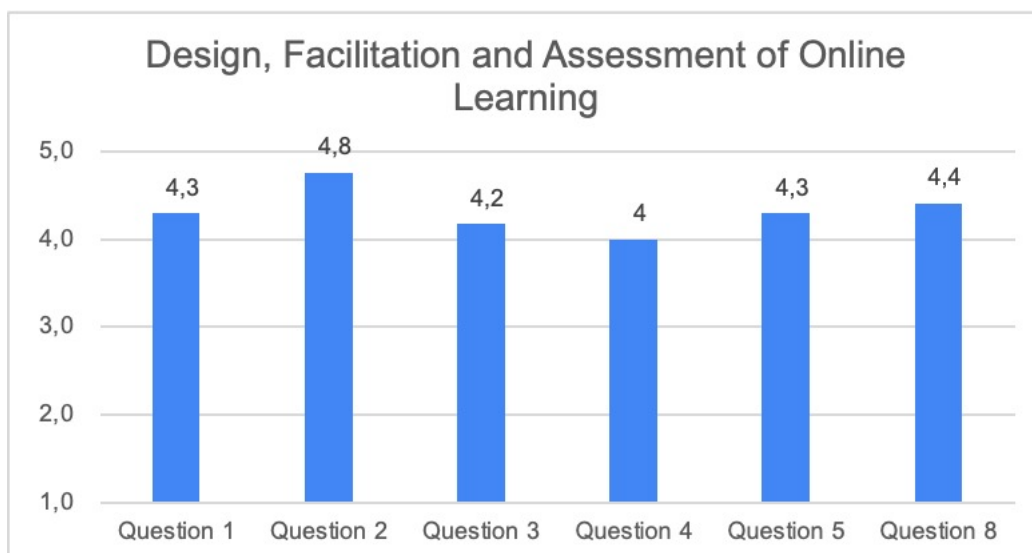


Figure 5. Results from participants in the training session “Assessment and Feedback in Active Learning”

The qualitative data highlighted the trainer's knowledge and ability to motivate participants as key strengths. Participants appreciated the trainer's availability to clarify doubts and the dynamism in the sessions. In terms of the knowledge transfer and skills developed, participants refer that they plan to improve the use of Moodle by applying their knowledge to create more interactive and dynamic materials, such as tests, videos, and quizzes. On the one hand, the practical component of the course was noted as a strength, with participants enjoying the hands-on exercises and the opportunity to practice what was presented during the sessions. On the other hand, participants noted that time constraints and the overload of activities made it difficult to fully engage with and complete all tasks. These quotes reflect the participants' plans to enhance Moodle usage, incorporate interactive and dynamic tools, and gradually implement these strategies into their teaching practices.

Strong points: Trainer's competence and availability; approach to innovative teaching strategies very useful for teaching; dynamism of activities/tasks proposed.

Use tools to improve the structure/presentation of theoretical content, creating interactive instruments (videos with questions/challenges, educational games).

Weak points: Too many requests/formulations of exercises within exercises.

Weak points: limited personal availability, due to the accumulation of other professional tasks, for completing all the proposed asynchronous activities.

4 Discussion and Conclusion

The evaluation of the five pedagogical training sessions conducted at Portucalense University during the 2024/2025 academic year revealed a consistently high level of satisfaction among participating faculty members. Quantitative data indicated particularly strong ratings for the relevance of the content, the effectiveness and engagement of the trainers, and the practical applicability of the methodologies introduced. These results suggest that the training sessions were well-aligned with the professional development needs and teaching contexts of the participants. Among the sessions offered, “Gamification in the Classroom” and “Design, Facilitation, and Assessment of Online Learning” stood out not only for their high satisfaction ratings but also for attracting the highest number of participants. This trend underscores a growing institutional and

pedagogical interest in innovative teaching strategies that promote active student engagement and digital pedagogical competence. The attractiveness of these themes reflects a broader shift in higher education toward learner-centered approaches and the strategic use of educational technologies, especially in response to evolving student expectations and post-pandemic digital transformation in teaching practices. Moreover, the strong interest in these sessions may indicate that faculty members are seeking more flexible, interactive, and technology-enhanced teaching models to better support diverse learning styles and improve learning outcomes. This demand could guide future staff development initiatives, emphasizing continued support for digital pedagogy, student motivation techniques, and the design of hybrid or fully online learning experiences. The findings not only contribute to validate the current training approach but also provide direction for targeted future offerings that align with both institutional goals and faculty needs.

Qualitative feedback provided by the participants further reinforced the positive outcomes of the training sessions, revealing a clear and purposeful intention among faculty members to implement the acquired pedagogical strategies in their teaching practices. Many respondents described specific plans to integrate active learning methodologies such as gamification, project-based learning, collaborative activities, and the strategic use of digital tools into their curricular design. This perspective suggests that the training not only increased awareness of innovative approaches but also inspired actionable changes in teaching methods (Fernandes et al, 2023). The references to concrete classroom applications indicate that participants viewed the training as both relevant and immediately applicable. These intentions reflect a growing alignment between individual teaching practices and broader institutional priorities, particularly those related to enhancing student engagement, improving learning outcomes, and reducing dropout rates. The emphasis on methodologies that promote active participation and continuous assessment demonstrates a commitment to pedagogical innovation grounded in student-centered learning (ESG, 2015).

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Experience Integrating an Interdisciplinary Schema of Project Based Learning on an Engineering Program

Julio Urbano¹, José Ramírez¹, Esteban Rosero¹

¹ University of Valle, Faculty of Engineering, Electrical and Electronics Engineering School, Cali, Colombia

Email: julio.urbano@correounivalle.edu.co, jose.ramirez@correounivalle.edu.co, esteban.rosero@correounivalle.edu.co

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Abstract

Interdisciplinary connections are featured as key booster in a Project Based Learning curriculum implementation (Yusri et al., 2024). Supported by significant teachers' guidance and appropriate resources which are considered primary components in the Gold Standard Design of a Project, multiple related areas can be integrated in project activities to enhance the learning process and develop skills. This document presents the experience of integrating the courses of Instrumentation and Measurements, Communication Systems, and Control Systems in a Project Based Learning schema for an Electronics Engineering Program. The experience was mainly guided for the Control Systems course. Extending curriculum elements and resources presented in (Ramírez-Scarpetta et al., 2024), multiple activities aimed at integrating these areas were proposed and performed with the students in two consecutive academic periods (2024-I, 2024-II). Opinions from students were collected to assess the relevance of the schema and the level of alignment with the main elements of the project design in a curriculum. The assessment results highlight engagement and motivation from students showing how meaningful this schema could be in an Engineering program.

Keywords: Control Systems; Curriculum Implementation; Engineering Education; Interdisciplinary Connections; Project Based Learning.

1 Introduction

Control Systems is a field that requires interdisciplinary work (Rossiter et al., 2023) such as communication, instrumentation, digital processing signals, and others. With applications to multiple engineering fields, the study of control systems requires students to engage with real-world problems and hands-on activities. An effective education strategy is crucial to support this learning process and Project Based Learning (PBL) has been widely adopted for this purpose. Additionally, the integrative project strategy is being considered alongside PBL to further enhance the learning experience and facilitate the integration of multiple knowledge fields.

As is detailed in (Dos Santos et al., 2023), defining an integrative project with different knowledge areas involved presents a challenge. The problem definition, the assessment, the contents, and other curriculum elements are expected to be aligned properly. A unified effort of the pedagogical team is required to obtain optimal results.

This document presents an experience implementing PBL alongside the Integrative project strategy. The courses of Instrumentation and Measurements, Communication Systems, Communication Networks, and Control Systems were integrated in a Project Based Learning framework for an Electronics Engineering Program with the Control Systems as the leading course. Over two consecutive academic periods (2024-I, 2024-II) activities aimed to integrate these knowledge fields were proposed and performed with students. Curriculum elements were defined and resources presented in (Ramírez-Scarpetta et al., 2024) were used to support the learning experience. At the end of each academic period, students feedback was gathered to assess the relevance of the approach and its alignment with key project design elements in a curriculum.

The rest of this document is structured as follows: details about interdisciplinary courses are presented in section 2, elements of Project Based Learning including resources and materials are discussed in section 3, students' opinions and first assessment of the schema are presented in section 4, discussion and results are presented in section 5, and section 6 concludes the document.

2 Disciplinary Courses

Control Systems, Communications Networks, and Instrumentation and Measurements are courses taken by Electronic Engineering students at the University of Valle during their seventh semester in the program. While each course has its own specific objectives, they collectively support the development of an additional course called Engineering Project II. In this course, various activities including practical training are proposed to guide students through the development of a project that integrates knowledge from all these areas.

The study of control systems is divided into two courses, the first is taken in the sixth semester and the second in the seventh. Similarly, Communication courses span two consecutive semesters beginning in the sixth. In addition, students take Engineering Project I in the sixth semester, which aims to integrate the content from both the Control Systems and Communication courses

Figure 1 shows the connection of the courses of Communications, Control Systems, Engineering Project, and Measurements and Instrumentation for the Electronics Engineering program.

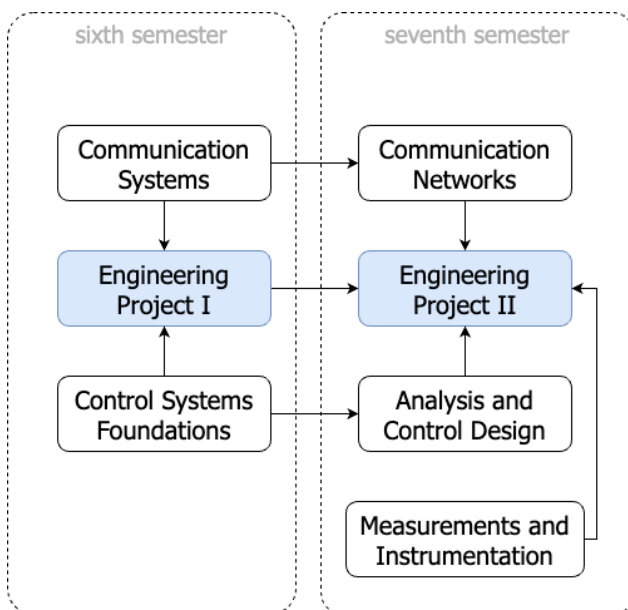


Figure 1. Communication, Control Systems, Engineering Project, and Measurements and Instrumentation courses connections.

The structure shown in Figure 1 enables interdisciplinary problems to be addressed as projects in an engineering context, supporting the development of transversal skills and reinforcing the knowledge in the related disciplines.

2.1 Communication Courses

Communication Systems and Communication Networks are two of three courses in the Communications field in the Electronic Engineering program at the University of Valle. These courses focus on various topics, including but not limited to physical transmission mediums, the OSI model, network applications, and the Internet.

Internet of Things applications (IoT) rely heavily on communication technologies (Behnke & Austad, 2024). Networked control systems applications also depend on robust communication to function effectively (Wang et al., 2024). Different factors such as transmission delays can significantly impact the performance of a controlled system. To integrate the fields of communications and control systems, students are expected to explore various characteristics of the communication infrastructure including reliability through hands-on activities.

The study of communications is supported by learning resources including simulations, animations, analysis tools, and physical devices. Hands-on activities are performed in class and practicing activities are proposed as training. Practical activities of the courses focus on programming and operating network devices such as routers and communication modules. Local area networks (LANs), both wired and wireless, are configured using physical devices where different protocols such as TCP and DHCP are applied to run network applications. Additionally, short-range point-to-point radiofrequency networks are explored through practical exercises.

2.2 Control Systems Courses

In Control Systems courses, students are expected to: define a problem or application; model a system in both continuous and discrete domains as well as input-output and state space representations; analyse the system in time and frequency domains using tools such as root locus and frequency response; define an appropriate expected performance for the system in closed loop operation; and design and implement controllers including a Proportional Integral Derivative (PID), RST, and state feedback (Ogata, 2001).

With the introduction of digital tools and digitally managed equipment such as data acquisition devices, being able to handle and process digital data has become an essential skill for students to develop. Data-driven techniques, such as those used for modelling, are introduced in the courses. Training in data preprocessing and cleaning, aimed at estimating numerical models of a system, is provided to students, particularly concerning modelling discrete representations.

Various learning resources are used to introduce concepts and bridge theory with practice in Control Systems courses. Computational notebooks in MatLab® (MatLab® Live Scripts) are used in class. MatLab® Live Scripts allows running code and embedding text and multimedia elements which students find engaging. Simulations, analysis, calculations, and more, can be included in these computational notebooks. Virtual laboratories are used for hands-on practice. Virtual laboratories enable students to experience the expected behaviour of a real control system in a simulated or emulated environment. Robust laboratory equipment; for example, a continuous current motor-based system, a tank level control system, a pressure control system, and portable prototypes, is used for practical training and project activities. Data acquisition devices, which are also learning resources available for students, connected to a computer allow them to measure systems' variables and use the measured variables to evaluate a compensation signal. MatLab® SimuLink offers libraries to work with different acquisition devices such as the National Instruments MyDAQ®. MatLab® SimuLink and portable data acquisition devices, together, allow the creation of a practical environment for deploying control systems where any type of controller can be implemented digitally.

To integrate knowledge from Communication Systems and Instrumentation, the control system elements, including the controller, the actuator, the process, and the sensor, rely on additional equipment such as communication devices and instrumentation modules. Communication devices are used to connect control system elements located in different places. In (Ramírez-Scarpetta et al., 2024) applications connected to the Internet are presented. Communication modules are also employed to isolate some of the control system elements; for example, the controller and the actuator are connected using radiofrequency modules and they use the air instead of electrical wires as the transmission medium. The previous example enables applications

of IOT as discussed in (Ramírez-Scarpetta et al., 2024). Instrumentation is used with sensors to condition the output signal of the process ensuring it is suitable for the controller.

2.3 Measurements and Instrumentation

Measurement is a process of gathering information from physical variables while instrumentation is the use of measuring instruments to monitor and control processes.

The purpose of this course is to provide students with the basic tools for the conception and design of electronic measuring instruments based on given metrological and electrical specifications, taking into account the various physical, electrical, electronic, adaptation, and signal conversion aspects involved in an electronic measurement chain. To achieve this purpose, the student is expected to be able to: analyze the transduction mechanisms that can be used to sense a magnitude, select the best transducer in terms of what is to be measured and the measurement conditions, design the analog/mixed electronic system that improves the electrical signals delivered by the transducer considering the hardware restrictions, digitize the analog signals without losing relevant information, obtain digital readings in engineering units by applying filtering, linearization, compensation and resolution increase processes, and validate to guarantee the metrological specifications required in a particular solution.

For hands-on activities, students design, simulate, and build signal conditioners for different types of sensors. Students are expected to have experience working on both analog and digital devices, such as operational amplifiers and microcontrollers. Low-cost devices such as the Arduino platform, which is equipped with an analog to digital converter, are proposed for use. Additional available resources to support practical activities for the course include signal generators, power supplies, and multimeters.

3 Project Based Learning and the Engineering Project Courses

((Kolmos et al., 2009)) presented seven elements which must be aligned in a Project Based Learning curriculum design. These elements are: objectives and knowledge, types of problems and projects, progression and size, student learning, academic staff and facilitation, space and organization, and assessment and evaluation. Achieving alignment among these elements presents a significant challenge, particularly when multiple knowledge areas are involved. In such cases each element must be aligned individually including sub elements of those considered knowledge fields.

Each course within the framework does not implement Project-Based Learning independently; instead, PBL is integrated through the Engineering project courses. The activities in individual courses primarily consist of lectures and practical exercises, which do not directly promote active learning. The objectives of each course aim to build foundational knowledge in a specific area while also introducing students to applications related to the other disciplines.

The Engineering Project courses are highly focused on project development. Topics related to project design are introduced and developed within these courses. Lectures and materials provided for the courses aim to equip students with: projects management abilities including time-management, project conception, project execution, and so on; practical experience using the equipment from different disciplines and available learning resources to implement the project solution; financial analysis theory and tools; and practical knowledge of the integrated areas. Projects are divided into stages, each with different objectives. The first stage of the first course focuses on initiation and planning activities with conceptual and basic engineering. The second stage of the second course focuses on detailed engineering.

The context of the problems proposed to students is a control system application. Students work in teams to develop the project. Throughout the project, students are expected to develop transversal skills such as oral and written communication, teamwork, critical thinking, creativity, problems-solving, and others. By the end of the project, students implement the solution of the problem using the available equipment. For the first course, students are expected to use short range wireless modules to connect the controller and the actuator, and deploy a PID controlled system. In the second course, electronic instrumentation modules are used to create the measurement sensor of the control system, local area network devices are proposed to connect the control system elements, advanced controller algorithms, such as RST and state feedback, are desired to be deployed.

The academic staff of the framework is supported by six facilitators (teachers). Each Communications and Control Systems course has assigned one facilitator, with a total of two per area. The Measurements and Instrumentation area has a separate facilitator, while the two Engineering Project courses are supported by an assistant. Each semester, the facilitators of the disciplinary courses assist in the development of the Engineering Project courses, working alongside the assistant. The assistant is responsible for supporting practical activities, which involve training students to use the experimental equipment they will need for their projects.

The courses assess students through reports on the performed training activities, reports on the developed activities for each phase or stage of the project, and presentations of the progress at each stage. Training activities reports correspond to computational notebooks that include the results of the different experiments proposed to be carried out. Data of the simulations, calculations, and so on, generated in experiments is expected to be embedded in the notebooks. Training activities are performed on laboratory equipment. Each phase or stage of the project involves multiple training activities to be carried out before the deadline. Stage reports consist of written documents detailing the results and discussion of the activities proposed. Presentations are lecture-like speeches given by each team member to their peers and the teacher.

4 Students Opinions

The instrument to collect students' opinions was adapted from the quantitative analysis presented in (Alsmadi et al., 2024). In (Alsmadi et al., 2024), the Instructional Materials Motivation Survey (IMMS) (Keller, 2010) was employed to assess the motivational impacts of Problem-Based Learning (PBL) within a multidisciplinary framework. The statements used in the survey, listed in Table 1, were derived from the Motivation Survey. These statements are rated on a scale from 1 to 5 where 1 indicates strong disagreement and 5 indicates strong agreement.

Table 1. Questions of the survey.

ID	Question
Confidence	
Q1	After the initial phase, I felt more confident because I knew what I was going to do in the projects
Q2	The content of the disciplinary and project courses was easier to learn than I initially expected
Q3	For each phase of the projects, the deliverables were consistent with the expected scope of development
Q4	After working on the projects for a while, I felt confident I could pass the planned evaluations
Q5	After completing the project work, I felt confident I could apply it in my professional life
Attention	
Q6	From the initial phase, I became interested in the development of the projects
Q7	The projects were sufficiently practical and realistic, which helped sustain my interest in them
Q8	The way the projects were structured contributed to maintaining my engagement throughout their

	development
Q9	Learning activities such as readings, lectures, hands-on training, exercises, games, and animations supported my sustained interest in the projects
Q10	The project-based courses were engaging and enjoyable
Satisfaction	
Q11	Completing the tasks required by the projects gave me a sense of satisfaction with the achievement attained
Q12	I believe I acquired meaningful learning from both the disciplinary and projects courses
Q13	I genuinely enjoyed working on the projects
Q14	The feedback, evaluation, and comments received throughout the development of the project activities made me feel satisfied with the effort I invested
Q15	I enjoyed working on the projects so much that I look forward to engaging in similar projects in my professional career
Relevance	
Q16	From the initial phase of the projects, I was able to recognize the importance of working on projects
Q17	It is clear to me how the project developments are connected to topics I was already familiar with
Q18	The cases addressed within the projects were of significant relevance
Q19	I learned to perform more effectively within my team as a result of the situations encountered during the project work
Q20	What I learned through the project work will be highly valuable for my professional life

The survey was created using Google Forms and administered to students in class. A total of 9 students participated, all of whom had completed the sixth and seventh semesters and were currently enrolled in the eighth semester of the program at the time the survey was conducted. Demographic information, including ethnicity, age, and gender, was collected to record the respondents' characteristics. Ethnicity categories were based on the classification provided by the National Statistics Administrative Department (DANE) (DANE, n.d.) of the Republic of Colombia. Table 2 presents the demographic composition of the respondents.

Table 2. Demographic characteristics of the students.

Parameter	Genre		Age			Ethnicity		
	M	F	21	22	23	Colombian - African	Mixed	Unrecognized
Value	8	1	5	2	2	1	2	6

Figure 2 summarizes the survey results. The "Q" labels in the figure correspond to the questions listed in Table 1. The gray bars represent the average scores for each question. The red dashed lines indicate the overall average values for each level: 4.1 for confidence, 4.0 for attention, 4.2 for satisfaction, and 4.4 for relevance.

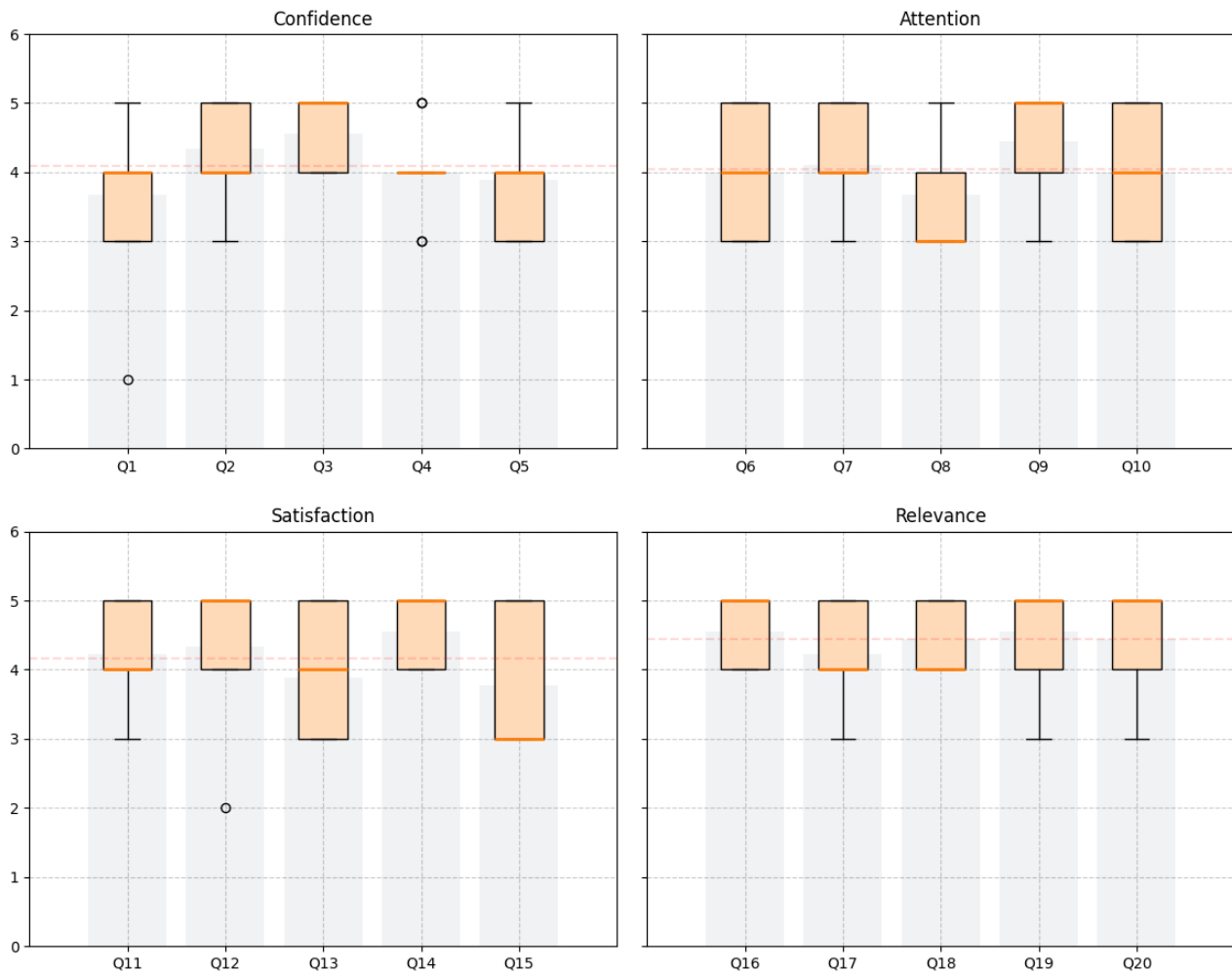


Figure 2. Summary of responses results.

5 Discussion

Most of the responses to each question show consistent variability, generally tending toward values higher than 3. This is considered an acceptable outcome given that this is the first assessment. Questions Q1 and Q12 received notably lower ratings. Question Q1 relates to the early stages of project development, where students are introduced to the project's scope and objectives, and are expected to gain confidence in carrying out the activities. Question Q12 assesses the level of satisfaction after reviewing the knowledge content from disciplinary and project courses. These lower ratings appear as outliers in figure 2 suggesting they are not entirely aligned with the overall response trends.

Questions Q6, Q10, Q13, and Q15 show higher variability. Similar to Q1, Q6 focuses on the initial phase of the projects but emphasizes the attention level. How confident and interested students feel at the beginning; these aspects should be highlighted for improvement in future courses. Questions Q1 and Q8 recorded the lowest average values. Q8 evaluates students' engagement throughout the project development, which may vary depending on the structure of the courses.

In terms of relevance, the results show a high median, with most responses above 4. This is an indicator that the framework could be engaging for students. Q17 received the lowest average score in the relevance level. This question concerns the type of problems and projects presented to students and whether they align with familiar topics covered in the program.

These results help identify specific elements of the framework that may require further attention. However, definitive conclusions cannot yet be drawn, as this is the initial assessment. Additionally, instrument validation is premature at this stage due to the small sample size of only nine responses. Further review is expected as more data becomes available.

6 Conclusion

This paper describes the experience of implementing a PBL and integrative project framework within an engineering program. The experience spans two academic periods, during which the Communications, Control Systems, and Instrumentation and Measurements courses were integrated and aligned to support the development of a new course called the Engineering Project, where the PBL and integrative project framework was deployed. The framework was mainly guided to the Control Systems courses. The implementation of this integrative project strategy, alongside Project-Based Learning (PBL), has been presented as a comprehensive framework for developing both technical and transversal skills in an Electronics Engineering program, and to integrate multiple knowledge areas.

An initial assessment of student acceptance was conducted through a survey, which evaluated four key dimensions: confidence, attention, satisfaction, and relevance. The results emphasize the meaningful impact this framework could have on students' engagement. Future evaluations will be conducted to draw more definitive conclusions about the framework's effectiveness and to refine the assessment tools.

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Identifying Key Course Units in Engineering Programs Through Grade Correlation Analysis

Leonidas Sandoval Junior¹, Fabio Orfali¹

¹ Insper, São Paulo, SP, Brazil

Email: leonidassj@insper.edu.br, fabioo1@insper.edu.br

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Abstract

Which course units in an engineering program are most correlated with performance in other units? Can early academic results predict future success or risk of dropout? This study analyzes final grades from a Computer Engineering program to identify correlations between course performance within and across semesters. By applying correlation analysis and network theory, we assess the centrality of key course units in influencing academic outcomes. Our findings reveal strong intra-semester correlations, particularly among courses emphasizing quantitative skills, and significant inter-semester correlations suggesting that performance in foundational subjects predicts future academic success. These insights are critical for academic management, as students with three or more failures in a single semester are held back, delaying graduation and substantially increasing dropout risks, especially among scholarship recipients. The results can guide curriculum development and inform targeted academic support strategies aimed at improving student retention and success.

Keywords: grade correlations, dropout risk, academic success, engineering education.

1 Introduction

Is there a way to predict the possibility of success of a student from his or her past grades? Is there an early warning that a student will drop out of higher education?

Predicting student success or identifying early signs of dropout in higher education has become a crucial area of research for institutions seeking to improve retention rates and academic outcomes. These issues not only affect students' personal and professional trajectories but also have broader implications for institutional credibility and funding efficiency, especially in cases involving scholarship recipients, where external stakeholders are also invested.

A comprehensive review by Kocsis and Molnár (2024), analyzing 95 studies published since 2012, highlights several reliable predictors of academic success and dropout risk. Among the most significant are prior academic performance indicators, such as Grade Point Average (GPA) or Cumulative GPA (CGPA). Demographic variables, particularly gender, with male students displaying a higher likelihood of dropping out, and non-academic factors, such as external workload, also play key roles.

Psychological and behavioral traits are equally important in predicting academic outcomes. The review points to intrinsic motivation, self-regulated learning strategies, self-efficacy, conscientiousness, and grit as substantial contributors to academic persistence and performance. These findings are echoed by Sandoval and Orfali (2024), who found that conscientiousness and concentration were positively correlated with student performance, reinforcing the role of psychological readiness and executive functioning in higher education success.

Gallego et al. (2021) conducted a cluster analysis on 284 first-year Health Sciences students at a Spanish university. Their findings indicate that students with both high cognitive skills and effective learning strategies (Cluster 1) significantly outperformed peers in GPA and credit accumulation, compared to those in Clusters 2

and 3, characterized respectively by cognitive aptitude but weak learning strategies, and low cognitive abilities with moderate strategy use. This underscores the interplay between ability and behavior in shaping academic outcomes.

From a broader institutional and policy perspective, Behr et al. (2021) explored the multidimensional causes of university dropout. They categorized influences into three tiers: macro-level (national education policy), meso-level (institutional practices and support systems), and micro-level (student-specific factors such as prior education and employment status). This layered framework offers a comprehensive lens through which dropout phenomena can be understood and addressed.

Finally, Nurmalitasari et al. (2023) identified a set of critical dropout factors specific to private universities in Central Java, Indonesia. These include financial constraints, academic dissatisfaction, low academic achievement, and the economic status of students' families. Their study highlights the urgent need for financial and academic support structures, especially in under-resourced educational contexts.

This article investigates the widely held assumption that previous academic performance serves as a reliable predictor of future success or failure in higher education. Specifically, it analyzes the final grades of students enrolled in a Computer Engineering program, aiming to identify correlations in academic performance both within the same semester (intra-semester) and across successive semesters (inter-semester).

The type of correlation being used is Pearson correlation, that establishes linear similarities between sets of data. In terms of final grades, if correlations between two sets of grades is high, then students with high grades in one set usually have high grades in the other set; conversely, students with low degrees in one set also tend to have low degrees in the other set. Low correlations indicate that there are no linear connections between grades obtained by students in one set with grades obtained by the same students in the other set. So correlations help one analyse how results in one course unit might be connected with results in other course unit.

Section 2 offers a detailed overview of the dataset, including the filtering criteria employed to ensure the reliability and consistency of the data. Section 3 presents a focused case study analyzing intra-semester correlations, providing insights into the relationships between student performance across course units within the same academic term. Section 4 explores inter-semester correlations, identifying course units whose outcomes appear to significantly influence student success in subsequent semesters. Section 5 examines potential relationships between the failure rates in courses offered during the program's second semester and the failures experienced by the same students in courses from the first semester

2 Data

The dataset used in this study comprises academic records from 687 students in the Computer Engineering program, 258 in Mechanical Engineering, and 380 in Mechatronics Engineering, after applying necessary data filtering procedures. The analysis spans nine semesters for each program, covering the academic periods of the second semester of 2023 and the first semester of 2024.

Correlations were computed using students' final grades, which reflect a weighted average of assessments including written exams, projects, quizzes, and class activities. Intra-semester correlations were calculated by selecting students who had valid final grades in all course units within a given semester. For inter-semester correlations, the analysis included only those students who had final grades in all course units for both semesters being compared. Pearson correlation was used in these analyses.

A total of 18 intra-semester correlation matrices and 8 inter-semester correlation matrices were generated for each of the three programs. Given the breadth of the dataset, this article will focus on presenting and discussing the results for the Computer Engineering program, which offers the largest sample size and most comprehensive data coverage. Section 6 presents conclusions and possibilities of further studies.

3 Intra-semester correlations

The first step in the analysis was to filter students who received final grades in a given semester. This procedure excluded a small number of students who withdrew from one or more course units before any grades were assigned.

Next, we constructed correlation matrices based on final grades to calculate intra-semester correlations. These matrices were built so that cell ij presents the correlation of final grades of course unit i with course unit j . To distinguish meaningful correlations from noise, we studied shuffled datasets where the order of the grades was randomized. From this, we observed that correlations below 0.5 are generally indistinguishable from random fluctuations. Thus, only correlations above 0.5 are considered significant in our analysis.

Data was accessed from two consecutive semesters, allowing us to build separate correlation matrices for Semester 2 of 2023 and Semester 1 of 2024. Comparing these matrices provides an estimate of the standard deviation between correlation values, which are always lower than 0.2, but most often lower than 0.1.

Tables 1, 2, and 3 show the results for the first, second and third semesters of the Computer Engineering program. Higher correlations are highlighted with boldface and larger numbers. The values presented are weighted averages across semesters, showing only the first significant digit.

Table 1. Correlations between final grades of the Course Units of the first semester.

First Semester	Software Design	Grand Challenges of Engineering	Instrumentation and Measurement	Modeling and Simulation of the Physical World	Design Nature
Software Design	1	0.4	0.6	0.6	0.2
Grand Challenges of Engineering	0.4	1	0.5	0.3	0.5
Instrumentation and Measurement	0.6	0.5	1	0.6	0.4
Modeling and Simulation of the Physical World	0.6	0.3	0.6	1	0.4
Design Nature	0.2	0.5	0.4	0.4	1

Table 2. Correlations between final grades of the Course Units of the second semester.

Second Semester	Electrical Drives	Co-Design of Apps	Data Science	Physics of Motion	Mathematics of Variation
Electrical Drives	1	0.6	0.7	0.8	0.7
Co-Design of Apps	0.6	1	0.6	0.6	0.7
Data Science	0.7	0.6	1	0.7	0.7
Physics of Motion	0.8	0.6	0.7	1	0.9
Mathematics of Variation	0.7	0.7	0.7	0.9	1

Table 3. Correlations between final grades of the Course Units of the third semester.

Third Semester	Multivariable Mathematics	Deconstructing Matter	Agile Collaborative Development	System Elements	Computational Robotics
Multivariable Mathematics	1.0	0.6	0.7	0.6	0.6
Deconstructing Matter	0.6	1.0	0.7	0.6	0.7
Agile Collaborative Development	0.7	0.7	1.0	0.7	0.8
System Elements	0.6	0.6	0.7	1.0	0.7
Computational Robotics	0.6	0.7	0.8	0.7	1.0

Since correlation matrices are symmetric, the information above and below the diagonal is redundant.

From Table 1, significant correlations are observed among Software Design, Instrumentation and Measurement, and Modeling and Simulation of the Physical World. These course units are STEM-oriented (Science, Technology, Engineering, and Mathematics), reflecting interconnected skill sets involving programming, laboratory data handling, and modeling of physical phenomena.

In contrast, Table 2 shows much stronger correlations among second-semester course units, which are also heavily STEM-based. Notably, there is a very high correlation between Physics of Motion (covering kinematics and variation) and Mathematics of Variation (focusing on calculus, differential equations, and linear algebra). This suggests that students who perform well in one of these courses are highly likely to perform well in the other, and similarly for students with lower performance.

Table 3 show sizeable correlations between all course units, be them general course units of Engineering (Multivariable Mathematics and Deconstructing Matter) or more specific course units of the Computer Engineering Program.

Analysis of subsequent semesters (fourth to ninth) reveals a similar trend: strong correlations among STEM courses in earlier semesters, gradually weakening as students progress through the program. Correlations tend to be weaker among course units of semesters above four.

4 Inter-semester correlations

Further analysis was conducted on the correlations between students' final grades in course units across consecutive semesters. To perform this analysis, we further filtered the data, selecting only students who had final grades in all course units of both semesters being compared. Since we have only one dataset per correlation matrix, we do not report means or standard deviations for these values. Additionally, we focus exclusively on correlations between different semesters, resulting in asymmetric matrices.

Tables 4 and 5 present the correlation matrices: Table 4 shows correlations between the first and second semesters of the Computer Science program, while Table 5 presents correlations between the second and third semesters. Both tables also include two additional indicators inspired by complex network theory (Newman 2010): Out Node Strength and In Node Strength. In Table 4, for instance, the Out Node Strength of a first-semester course unit represents the sum of its correlations with second-semester course units. Conversely, the

In Node Strength of a second-semester course unit captures the sum of its correlations with first-semester course units.

Table 4. Correlations between final grades of first-semester and second-semester course units.

	Electrical Drives	Co-Design of Apps	Data Science	Physics of Motion	Mathematics of Variation	Out Node Strength
Software Design	0.6	0.6	0.8	0.7	0.8	3.5
Grand Challenges of Engineering	0.7	0.7	0.6	0.5	0.6	3.1
Instrumentation and Measurement	0.7	0.8	0.8	0.8	0.8	3.9
Modeling and Simulation of the Physical World	0.7	0.8	0.7	0.8	0.9	3.9
Design Nature	0.4	0.7	0.3	0.4	0.4	2.2
In Node Strength	3.1	3.6	3.2	3.2	3.5	

Table 5. Correlations between final grades of second-semester and third-semester course units.

	Multivariable Mathematics	Deconstructing Matter	Agile Collaborative Development	System Elements	Computational Robotics	Out Node Strength
Electrical Drives	0.5	0.5	0.6	0.3	0.1	2.0
Co-Design of Apps	0.5	0.4	0.4	0.3	0.1	1.7
Data Science	0.4	0.7	0.5	0.5	0.2	2.3
Physics of Motion	0.9	0.6	0.7	0.5	0.2	2.9
Mathematics of Variation	0.9	0.5	0.8	0.4	0.2	2.8
In Node Strength	3.2	2.7	3.0	2.0	0.8	

From Table 4, Instrumentation and Measurement stands out with the highest Out Node Strength, closely followed by Modeling and Simulation of the Physical World. It is also worth highlighting the particularly strong correlation between Modeling and Simulation of the Physical World and Mathematics of Variation. Regarding In Node Strength, Co-Design of Apps, which is a highly project-based, user-centered course, emerges as the most impacted course unit of the second semester.

Looking at Table 5, strong correlations are evident between the second-semester units Physics of Motion and Mathematics of Variation with the third-semester unit Multivariable Mathematics. Notably, Multivariable Mathematics also has the highest In Node Strength, followed by Agile Collaborative Development, a course unit specific to Computer Engineering. Physics of Motion and Mathematics of Variation again show the highest Out Node Strengths.

According to the literature, course units with high Out Node Strength act as key determinants of student success in subsequent semesters. Students achieving high grades in these courses are more likely to perform well in following semesters. Conversely, students who underperform in these critical courses may be at higher risk of academic difficulties or even dropout, suggesting the need for early support and intervention strategies.

5 Determinants of the risk for dropout

Failures in multiple course units are among the main factors contributing to student attrition in higher education, particularly when they occur within the first two years of undergraduate programs (Cabello & Chagas, 2021; Aulck et al., 2016). Thus, the early identification of students with a high probability of failure can serve as an important tool for academic management, enabling the implementation of more effective measures to combat dropout rates, such as offering targeted academic support.

The course units offered during the second semester of the Computer Engineering program present significant challenges for a considerable portion of students, consistently showing the highest failure rates within the program (an analysis of progression to the third semester indicates a significant drop in multiple failures). Therefore, this study investigates the extent to which failures in first-semester courses influence subsequent failures in the second semester.

Table 6 presents the failure rates in second-semester courses among different groups within the studied population. Only those second-semester courses with failure rates above 5% were included in the analysis. Failure rates among students who failed Design Nature or Instrumentation and Measurement in the first semester were not analysed because none of the students in the studied group were retained in these courses.

As examples, Electrical Drives had a failure rate of 62% of the students considering the total number of students in the second semester. Of those who failed that course unit, 88% had also failed the first semester course unit Software Design. Of those who failed Electrical Devices, 100% had also failed Grand Challenges of Engineering and Modeling and Simulation of the Physical World. Difference from total indicates the difference between percent failures in a course unit of the first semester and a course unit of the second semester.

Table 6. Failed courses in the second semester compared with failed courses in the first semester of Computer Engineering.

Failed Course (second semester) →	Electrical Drives	Data Science	Physics of Motion	Mathematics of Variation
Relative to the total second-semester cohort	62%	38%	38%	24%
Among students who failed Software Design (first semester)	88%	88%	63%	63%
Among students who failed Software Design (difference from total)	(+26%)	(+50%)	(+25%)	(+39%)
Among students who failed Grand Challenges of Engineering (first semester)	100%	75%	50%	50%
Among students who failed Grand Challenges of Engineering (difference from total)	(+38%)	(+37%)	(+12%)	(+26%)
Among students who failed Modeling and Simulation of the Physical World (first semester)	100%	100%	100%	100%
Among students who failed Modeling and Simulation of the Physical World (difference from total)	(+38%)	(+62%)	(+62%)	(+76%)

The data suggest that *Modeling and Simulation of the Physical World* plays a central role in predicting failures during the second semester. In the studied cohort, every student who failed *Modeling and Simulation* subsequently failed all four second-semester courses analyzed. As this course integrates foundational concepts from Mathematics, Physics, and Programming through a project-based approach, poor performance may serve as a strong indicator that a student will struggle further in the second semester, where these concepts are addressed with a higher level of formalism.

Additionally, it is noteworthy that failure rates in *Data Science* are markedly high among students who failed *Software Design*, likely because many activities in *Data Science* demand programming skills developed in *Software Design*.

Students who fail any first-semester course and proceed to the second semester already face additional challenges, as they must balance the demands of new coursework while retaking courses they previously failed. Moreover, the findings suggest that failures in specific first-semester courses are particularly critical, highlighting the importance of targeted interventions, such as reinforcement programs, to mitigate the risk of further academic difficulties in the second semester.

6 Conclusion

This study highlights the importance of early academic performance as a predictive factor for future success or risk of dropout in Engineering programs. By analyzing correlations between final grades across the first three semesters of the Computer Engineering program, we identified specific course units that play pivotal roles in shaping students' academic trajectories.

Intra-semester analyses reveal that STEM-oriented courses, particularly those emphasizing Mathematics, Physics, and Programming, exhibit strong grade correlations, suggesting shared cognitive demands. Inter-semester analyses further demonstrate that performance in foundational courses, notably *Modeling and Simulation of the Physical World* and *Instrumentation and Measurement*, is strongly associated with success in subsequent semesters.

Moreover, the findings point to a heightened risk of academic failure in the second semester for students who struggle with key first-semester courses. In particular, students failing *Modeling and Simulation of the Physical World* exhibited substantially higher failure rates across all major second-semester course units, underscoring the need for targeted early interventions.

Identifying students at risk based on early academic indicators allows institutions to implement support strategies, such as remedial programs, tutoring, or personalized mentoring, thereby improving student retention and academic success.

Future research could expand the analysed data to cover longer time periods, allowing for an investigation into whether the observed patterns persist across different cohorts. We have data for all semesters of the Engineering courses and could use them.

Additionally, they could include students from Mechanical and Mechatronics Engineering programs, enabling a comparison with the results from Computer Engineering. Finally, such studies could assess the effectiveness of interventions aimed at mitigating the effects of failures in first-semester courses.

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Applying Project-Based Learning (PBL) to Enhance Engineering Education: A Case Study on Production System Design at the University of Brasília

Marcelo Carneiro Gonçalves^{1*}, Maria Gabriela Mendonça Peixoto¹, Gustavo Alves de Melo², Eugenia Cornils Monteiro da Silva¹, Simone Borges Simão¹

¹ University Brasília (UnB), Industrial Engineering Departament, Brasília, Brazil.

² Federal University of Viçosa (UFV), Industrial Engineering Departament, Viçosa, Brazil.

Email corresponding author*: marcelo.goncalves@unb.br

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Abstract

The implementation of Project-Based Learning (PBL) in engineering courses is essential to bridge the gap between theoretical knowledge and real-world application. This study presents an applied PBL approach in the Production System Design course at the University of Brasília (UnB), focusing on a real-world challenge faced by a recycling cooperative. The pedagogical strategy is structured in five rounds, where students progressively develop a comprehensive solution for a real industrial problem, integrating systematic problem-solving techniques, data analysis, and sustainability principles. The course methodology starts with a problem definition phase, where students conduct interviews and apply empathy maps to deeply understand the stakeholders' needs. The problem addressed in this iteration involved tracking the flow of recyclable materials at the Recicla+ Brasil cooperative, which faces operational and logistical inefficiencies. Throughout the course, students analyze the root causes using Ishikawa diagrams and the 5 Whys technique, propose solutions through a design-thinking approach, and implement prototypes tested in real conditions. Assessment is performed through rubrics for each round, evaluating problem comprehension, analytical depth, and implementation feasibility. The final round includes a technical report consolidating findings, stakeholder feedback, and a roadmap for project continuity. Results show that students develop critical thinking, problem-solving, and teamwork skills, while the cooperative benefits from structured improvements in its operations. This case study highlights the impact of active learning methodologies in engineering education and the social relevance of student-driven solutions. It also demonstrates how PBL fosters engagement, technical expertise, and a systemic perspective in addressing real industrial challenges.

Keywords: PBL; Active Learning; Sustainability; Production System Design.

1 Introduction

Engineering education is currently facing the challenge of preparing professionals capable of acting in increasingly complex, dynamic, and interdisciplinary environments. Traditional approaches, heavily based on lectures and fragmented content delivery, often fall short in developing essential skills such as critical thinking, collaboration, autonomy, and problem-solving. In response to these limitations, Active Learning methodologies have gained relevance in engineering curricula by promoting student-centered strategies that engage learners in the construction of knowledge through real-life problem-solving contexts (Decker et al., 2025; Kumar et al., 2025; Gonçalves et al., 2020; Ren et al., 2025; Junior & Goncalves, 2019).

Among active learning approaches, Project-Based Learning (PBL) stands out as an effective pedagogical strategy that bridges the gap between theory and practice. By structuring the learning process around the development of projects grounded in authentic challenges, PBL fosters not only technical competencies but also interpersonal and systemic thinking skills that are crucial for engineering professionals (Dhungana et al., 2025; Theissler et al., 2021; Shafi et al., 2018; Muideen et al., 2023; Bodenhausen et al., 2022).

This paper presents a case study from the Production System Design course at the University of Brasília (UnB), which applies a PBL methodology structured in five rounds. The project centers on a real-world problem faced

by Recicla+ Brasil, a recycling cooperative that struggles with logistical inefficiencies and lack of traceability in its operations. By engaging students in the analysis, design, and proposal of a feasible solution to this challenge, the course aimed to integrate active learning with sustainable engineering practices.

The goal of this study is to describe the pedagogical approach applied, analyze the learning outcomes for students, and reflect on the societal impact of the project. This initiative demonstrates how active learning methodologies can enhance engineering education by fostering deeper engagement, meaningful learning, and social responsibility in the training of future engineers.

2 Theoretical Framework

2.1 Active Learning Methodologies in Engineering Education

The increasing complexity of engineering problems and the demands of the labor market have highlighted the need to reform traditional teaching models in engineering education. Active Learning has emerged as a key pedagogical approach to foster student engagement, autonomy, and the development of transferable skills such as teamwork, communication, and critical thinking. This approach shifts the focus from the teacher as the central figure to students as active agents in the learning process (Cherdo et al., 2023; Tabit et al., 2022; Jain, & Tarey, 2023; Gopalakrishnan & Kumaran, 2022; Singh, Batheri & Dias, 2023).

Project-Based Learning (PBL) is one of the most prominent forms of Active Learning in engineering education. It involves the integration of knowledge across multiple disciplines through the development of structured projects that simulate real-world challenges (Voronov, Krysanter & Frisk, 2020; Redondo et al., 2020; Jain et al., 2020; Vianna et al., 2024). Unlike traditional problem-solving exercises, PBL emphasizes the process of learning by doing, encouraging students to investigate, design, prototype, and evaluate their own solutions (Gonçalves et al., 2023; Hamasaki et al., 2023; Labiod et al., 2025).

According to Shirole et al. (2025), PBL shares commonalities with other student-centered approaches like CDIO (Conceive, Design, Implement, Operate), particularly in its emphasis on interdisciplinary integration and competence development. In the PBL model, students work in teams to define problems, gather and analyze data, develop potential solutions, and reflect on their decisions and outcomes.

The pedagogical benefits of PBL are well documented in engineering literature. James et al. (2013) highlight that PBL enhances students' motivation and responsibility, promoting deeper learning and better retention of concepts. Hastie et al. (2009) also argue that PBL aligns well with the philosophical foundations of engineering education, promoting the formation of ethical, autonomous, and socially responsible professionals.

The adoption of PBL in engineering courses allows for a dynamic and reflective learning environment, where students not only acquire technical knowledge but also learn to deal with uncertainty, negotiate solutions with stakeholders, and work collaboratively under real constraints. This makes PBL particularly suitable for fostering 21st-century competencies and bridging the gap between academia and the professional world (Chen et al., 2018; Shingo, 1996; Zhang et al. 2025; de Faria et al., 2019; Zonta et al., 2020).

2.2 Sustainability and Engineering Practice

Sustainability has become a central theme in engineering education, driven by the urgent need to address environmental degradation, social inequality, and economic imbalance. Engineers today are expected not only to design efficient systems and technologies but also to contribute actively to the creation of sustainable societies. This broader responsibility requires integrating environmental, social, and economic dimensions into

the curriculum, promoting a holistic understanding of engineering solutions (Burmeister et al., 2023; Saaty, 2005; Stankevecz et al., 2019).

Incorporating sustainability into engineering education entails more than teaching environmental concepts. It involves fostering values such as social responsibility, ethical awareness, and systemic thinking. According to UNESCO's vision for sustainable development education, engineers must be equipped to design inclusive, responsible, and resilient solutions that address both human and planetary needs (Lin, Walker & Agarwal, 2025; Lourenço et al., 2023).

One of the key challenges in this integration is demonstrating to students how engineering decisions can directly influence real communities. Project-Based Learning offers a practical avenue for connecting sustainability principles with engineering practices. When students work on real-world problems—such as waste management, resource efficiency, or social inclusion—they develop a contextualized understanding of sustainability that goes beyond abstract theory (Karthikeyan et al., 2024; Prytz et al., 2015).

In the context of this study, the collaboration with Recicla+ Brasil—a recycling cooperative located in a vulnerable region of Brasília—provided students with an opportunity to engage in a socially and environmentally relevant project. The cooperative faces structural and operational challenges that limit its ability to track and process recyclable materials efficiently. By supporting the cooperative through data-driven solutions and low-cost interventions, students not only applied engineering principles but also contributed to environmental sustainability and the social inclusion of waste pickers.

This approach resonates with the concept of socio-productive sustainability, which emphasizes inclusive economic models that empower marginalized groups while promoting environmental care. Engineering education, when connected to community-based challenges, becomes a catalyst for sustainable transformation, aligning technical education with the United Nations Sustainable Development Goals (particularly SDG 4 – Quality Education and SDG 12 – Responsible Consumption and Production).

3 Target Stakeholders Methodology

This research is based on a qualitative case study developed within the Production System Design course of the Industrial Engineering undergraduate program at the University of Brasília (UnB). The course adopted a Project-Based Learning (PBL) approach to connect students with a real-world challenge involving a local recycling cooperative, Recicla+ Brasil. The pedagogical structure was organized into five progressive rounds throughout the semester, each corresponding to a distinct phase of the project development process and culminating in specific deliverables and evaluations.

The first round focused on problem definition. Students conducted interviews with the cooperative's administrative staff and developed empathy maps to understand the needs, expectations, and frustrations of stakeholders involved in the recycling operation. This initial engagement enabled students to immerse themselves in the context and clearly define the central problem to be addressed—namely, the lack of traceability in the flow of recyclable materials. In the second round, students applied analytical tools such as the Ishikawa diagram (Ishikawa, 1990) and the 5 Whys technique to investigate the root causes of the inefficiencies identified. This phase fostered the development of critical and systemic thinking and supported the ideation of feasible alternatives to address the problem.

In the third round, students formulated their proposed solutions and detailed an implementation plan. The proposals were developed using design thinking principles and justified through the 5W2H method, which helped structure the "what," "why," "how," and "who" aspects of each action. The solution designed by the

group involved two complementary fronts: a physical organization system for sorting the materials based on their origin, and a digital platform for collecting and analyzing operational data through Google Forms and Looker Studio dashboards. In the fourth round, students developed a preliminary prototype of the solution and generated mock dashboards using fictitious data to simulate system behavior. Although full implementation was limited by external constraints—including loss of direct contact with the cooperative—students were able to design and validate the technical feasibility and usability of their proposed system.

Finally, in the fifth round, students consolidated their project in a technical report, which included a summary of activities, critical reflections on the process, and suggestions for project continuity. Throughout the course, the evaluation process followed a rubric-based model, with criteria assessing students' problem understanding, analytical depth, teamwork, communication, and solution feasibility. These assessments were both formative and summative, providing students with continuous feedback and opportunities for iteration.

The methodology adopted in this course promoted the integration of technical knowledge with social responsibility, enabling students to apply engineering tools in a real community setting. Furthermore, it fostered the development of essential skills such as collaboration, creativity, data analysis, and structured decision-making. The use of a real-world challenge as the core of the learning experience made the learning process meaningful, while also contributing to a broader societal impact through the potential improvement of sustainable practices within the cooperative.

4 Case Study: Production System Design Course at the University of Brasília

The application of the Project-Based Learning (PBL) methodology was carried out in the Production System Design course offered by the Industrial Engineering program at the University of Brasília (UnB) during the second semester of 2024. The course aimed to engage students in solving a real-world problem faced by Recicla+ Brasil, a recycling cooperative located in the Paranoá region of the Federal District. The cooperative plays a central role in inclusive waste collection, environmental protection, and income generation for vulnerable populations. However, it faces operational challenges, particularly the absence of a structured system for tracking the origin and processing of recyclable materials.

The course was structured around five iterative rounds, each designed to guide students through progressive stages of project development. In the first round, students conducted interviews with the cooperative's leadership and developed empathy maps to understand the perspectives, needs, and frustrations of stakeholders. This immersion enabled the identification of key problems, including the lack of traceability of incoming materials, poor spatial organization within the warehouse, and the need for performance indicators to guide decision-making.

Building on these findings, students advanced to the second round, where they used the Ishikawa diagram and the 5 Whys technique to explore the root causes of the identified issues. The analysis revealed a combination of factors, such as limited infrastructure, insufficient formal procedures, absence of data collection mechanisms, and informal communication among staff. These elements contributed to inefficiencies in sorting, storing, and monetizing the recyclable materials.

In the third round, students proposed a solution that combined physical reorganization of the warehouse space with digital data management. The physical component involved the use of low-cost colored markers and fences to designate specific areas for materials from different collection points. This visual system aimed to simplify the sorting process and reduce material mixing. The technological component consisted of a Google

Forms-based data entry system, in which cooperative members could log key operational data such as date, number of workers, volume of material received, volume triaged, and destination of each load. The collected data was then integrated into a Google Sheets database, which powered a dynamic dashboard created in Looker Studio.

This dashboard allowed the cooperative to monitor essential performance indicators, including triage productivity per worker, volume of materials processed per day, material donation rates, and delivery schedules. Through these visual insights, cooperative managers could make more informed operational decisions, identify process bottlenecks, and optimize resource allocation.

By the final rounds, students refined their proposal and compiled a technical report presenting the full solution, supported by data visualization models and implementation strategies. The report included a 5W2H plan detailing actions, responsible parties, required resources, and proposed timelines. The proposed system aligned with the cooperative's sustainability objectives, enhanced transparency and efficiency, and contributed to the development of a data-driven operational culture.

This case study illustrates how engineering education can be enriched through real-world engagement. The experience enabled students to apply theoretical knowledge to complex, context-specific challenges, while contributing to the broader goal of socio-environmental sustainability. Moreover, the interdisciplinary nature of the problem stimulated collaboration, creativity, and a sense of social responsibility among future engineers.

5 Conclusion

The integration of Project-Based Learning (PBL) into the Production System Design course at the University of Brasília provided valuable insights into how active methodologies can transform engineering education. Through the engagement with a real and socially relevant challenge, students experienced the full cycle of problem-solving—from understanding stakeholder needs to proposing feasible technical and organizational solutions. This approach not only reinforced academic content but also fostered the development of critical skills aligned with the demands of contemporary engineering practice, such as teamwork, analytical reasoning, communication, empathy, and decision-making under constraints.

The partnership with Recicla+ Brasil highlighted the potential of engineering education to generate positive social and environmental impacts. The proposed solution, combining physical space organization and digital data management, addressed concrete operational inefficiencies and offered a replicable model for similar cooperatives. It also introduced students to the principles of sustainability from a practical and systemic perspective, making them reflect on how engineering decisions can influence inclusive economic development, waste reduction, and social equity.

The pedagogical outcomes of the course confirmed the effectiveness of PBL in enhancing student motivation and engagement. Working on a real-world project gave meaning to the learning experience and stimulated a higher level of responsibility and initiative. The five-round structure ensured progressive immersion, while the use of design and analysis tools such as empathy maps, Ishikawa diagrams, and 5W2H planning supported structured learning. The continuous assessment model, based on rubrics and iterative feedback, allowed students to reflect on their progress and improve their deliverables across rounds (Joseph et al., 2024; Burmeister et al., 2023).

From an institutional perspective, the case reinforces the importance of building university-community partnerships that bring mutual benefits: while students gain experience and practical knowledge, local stakeholders receive innovative and tailored contributions to their operational challenges. This dynamic aligns

with the broader goals of engineering education in the 21st century, which include not only technical excellence but also social responsibility, innovation, and sustainability (Rana et al., 2024; Stankevecz et al., 2019).

In addition to the technical outcomes, the project provided valuable opportunities for students' personal and professional development. Throughout the five rounds, students reported significant learning experiences, including improvements in teamwork, communication, and the ability to apply engineering tools in real contexts. Some students highlighted the challenge of adapting theoretical knowledge to the limitations of the cooperative's operational reality, mentioning that "working with a real client made us realize the importance of listening and adjusting our proposals based on stakeholder feedback." Others emphasized the growth in critical thinking, with comments such as "understanding the root causes was not just about using tools like the Ishikawa diagram, but about questioning assumptions and validating information directly with the cooperative members." These reflections demonstrate how the PBL approach fostered not only technical competence but also a heightened sense of social responsibility and problem-solving resilience.

In conclusion, this experience demonstrates that PBL can serve as a powerful educational strategy in engineering curricula. When connected to real societal challenges, it promotes a more meaningful and holistic learning environment. The case of Recicla+ Brasil illustrates how future engineers can be agents of transformation, capable of designing solutions that are not only technically sound but also socially inclusive and environmentally responsible. The outcomes of this project point to the relevance of expanding such initiatives across engineering programs, encouraging the adoption of methodologies that place learning, context, and community at the center of academic practice.

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PAEE/ALE'2025 Full Papers – Students' Award Submissions

Submissions accepted for the PAEE/ALE'2025 Students' Award.

Hands-On Activity in 3rd Year Industrial Engineering and Management: Students' Perspective

Beatriz Silva¹, Inês Silva¹, Maria Pereira¹, Maria Inês Torres¹, Marta Ribeiro¹, Raquel Oliveira¹, Sandra Costa¹, Anabela Alves^{1, 2}

¹ Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal

² ALGORITMI/LASI Research Center, School of Engineering, University of Minho, Guimarães, Portugal

Email: a104680@alunos.uminho.pt, a104681@alunos.uminho.pt, a104764@alunos.uminho.pt, a104768@alunos.uminho.pt, a104773@alunos.uminho.pt, a104694@alunos.uminho.pt, a104776@alunos.uminho.pt, anabela@dps.uminho.pt

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Abstract

This paper presents a hands-on classroom activity designed to simulate a production system using a baton-touch operating mode in the course of Production Systems Organization. The activity was carried out by a team of students of third-year Industrial Engineering and Management as part of an interactive learning experience aimed at understanding production processes and enhancing teamwork skills. In this simulation, students worked in teams to replicate the operations of a textile company (chosen by the team), focusing on identifying current situation, improving workflow and layout, resource allocation, and process management. The exercise was structured to challenge students to apply theoretical knowledge to a practical scenario and learn tools (e.g. Product-Quantity Analysis, SIPOC and Spaghetti diagram, balancing methods, Standard Work Sheets, Skills Competences), encouraging critical thinking and problem-solving skills. The teams had to define the demand and production rates, sustainable operations, and ensuring product quality throughout the process. Feedback from the activity highlighted its effectiveness in providing a practical understanding of textile production operations. Students reported a deeper appreciation for the complexity of production systems and the importance of communication and coordination among team members. The hands-on approach not only reinforced theoretical concepts but also emphasized the significance of adaptability and efficient problem solving in industrial environments. Overall, this activity provided valuable experiential learning, offering students a comprehensive insight into textile manufacturing while fostering teamwork, leadership, and operational efficiency.

Keywords: Active Learning; Industrial Engineering and Management Education; Project Based Learning.

1 Introduction

Active learning fundamentally differs from passive learning by positioning the student as the protagonist of their own educational process. While passive learning is characterized by the unidirectional reception of information, where the student assumes the role of a listener and content receiver, active learning involves dynamic participation, encouraging students to interact, question, and apply the knowledge acquired in practical contexts. This approach promotes a deeper and more meaningful understanding, facilitating retention and the ability to apply knowledge in real-world situations (Felder & Brent, 2006).

In recent years, active learning has expanded beyond traditional formats to include methodologies such as Design Thinking, gamification, and project-based learning, each aiming to increase student engagement and promote the development of higher-order thinking skills. Design Thinking, in particular, has shown to be effective in fostering creativity, empathy, and interdisciplinary collaboration among students (Alvarado, 2025). Similarly, the use of games and digital tools, commonly referred to as Game-Based Learning (GBL), has proven to enhance motivation, participation, and the ability to apply knowledge in dynamic scenarios, while also contributing to digital literacy (Rodríguez-Ferrer et al., 2023).

These active methodologies have also been linked to improved student well-being and preparation for professional challenges. By engaging students in real-life simulations and problem-solving tasks, active learning strategies cultivate key skills such as communication, teamwork, and decision-making. Furthermore,

research shows that active engagement in academic activities increases satisfaction and supports emotional, social, and academic well-being (Ribeiro-Silva et al., 2022). The implementation of such strategies, especially when integrated with technological resources, creates a flexible and interactive learning environment, reinforcing the pedagogical value of student-centered education.

In engineering education, active learning methodologies have gained increasing relevance for their capacity to foster engagement, critical thinking, and autonomy among students. Within this context, the Production Systems Organization (PSO) course integrates hands-on activities and Project-Based Learning (PBL), often in collaboration with real companies. These methods have proven particularly effective, placing students at the centre of the learning process and encouraging them to identify real-world problems and design practical, feasible solutions.

Within the scope of the Production Systems Organization course, the implementation of active learning methodologies, such as hands-on activities and Project-Based Learning in partnership with a company, has proven to be particularly effective. This methodology places students at the centre of the educational process, assigning them the responsibility of identifying real-world problems and developing practical solutions, fostering essential skills for the job market.

In PSO course, these methodologies have been used, emphasizing the importance of engaging students in projects that reflect real industrial challenges (Alves & Soares, 2020; Soares & Alves, 2019, 2021a, 2021b). The teacher of this course had been publishing the results of the feedback questionnaire fulfilled by the course students regarding this pedagogical experience. However, in these references were the results from the teachers' perspective. In this context, this paper discusses this pedagogical experience and its results from the students' perspective. The paper authors are, mainly, a student team that developed the assigned project aligned with this active approach, challenging the team to apply the concepts learned in a real industrial setting.

The motivation for this work stems from the team's participation in the PSO course project, which challenged students to reconfigure an existing production system using Lean principles. The team chose to work with a real company and focused on transforming a traditional production layout into manufacturing cells, adopting the baton-touch operating mode. This choice required the application of theoretical tools to real constraints and encouraged the development of decision-making, problem-solving, and technical skills in a practical context.

The main objectives of this paper are to describe the development of the hands-on activity from the student team's perspective, highlight the tools and methodologies applied throughout the project, and reflect on the skills acquired during this process. In addition, the paper aims to demonstrate the pedagogical value of engaging with real industrial environments and how active learning strategies can enhance both academic learning and professional preparedness.

This paper is organized in five sections. The first one is the introduction, where the objectives are presented. The second section outlines the study context. The third section presents the project development and hands-on activity preparation as well as the methodology adopted by the team, including company selection, analysis of the production system, the reconfiguration process, the lessons learned and hands-on simulation preparation. The fourth section presents the results and discussion, focusing on the simulation model, its implementation, and impact. Finally, the fifth section draws the main conclusions and highlights the competencies acquired and the pedagogical value of this hands-on learning experience.

2 Study Context

Production Systems Organization is a curricular unit offered in the 3rd year, 1st semester of the Industrial Engineering and Management degree at the University of Minho. This curricular unit aims to provide students with the necessary knowledge and tools to analyse, design, and improve production systems, focusing on efficiency, sustainability, and innovation. Through theoretical foundations and practical applications, PSO enables students to develop a comprehensive understanding of production management and process improvement.

The course assessment methodology combines theoretical quizzes to evaluate students' knowledge and understanding of key concepts, as well as a company-based project that allows them to apply these concepts in a real-world setting. The proposed work was to be developed by teams of seven to eight members, promoting collaboration and knowledge exchange among participants. This involved conducting a detailed diagnosis of a company's production system, considering production factors, transformation processes, and products (goods and/or services).

To achieve this, an initial research phase was carried out using indexed databases such as Scopus and Web of Science to provide a theoretical foundation for the analysis and proposed solutions. This was the first of three milestones for this project, completed in week 6 of the course. During this phase, teams had to prepare two A3 reports, summarizing scientific articles on the design and reconfiguration of production systems, such as assembly lines, cells, and job shops. More about this activity could be seen in Alves, 2020.

Subsequently, students' teams were required to choose between creating a fictitious company or working with an existing one to collect data and analyse its current situation. They were tasked with providing a critical assessment of its operations to identify waste, problems, and their underlying causes. Week 10 marked the completion of the second milestone, which involved an intermediate presentation of their findings, also following the format of a 5-minute presentation and a 5-minute discussion.

Finally, the third milestone, taking place in the 16th and final week, was the culmination of the project, in which teams proposed improvement strategies for the company or sector, supported by a cost-benefit analysis. The application of the 10R principles (Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover, and Refuse) (Kirchherr & Piscicelli, 2019; Potting et al., 2017) was also emphasized to ensure a positive impact on the sustainability of the production system. In addition to theoretical and diagnostic analysis, teams were also responsible for simulating the proposed production system, either by producing a prototype of the chosen product or through an alternative representation that demonstrated the implemented improvements. This final presentation lasted 30 minutes, followed by a 10-minute discussion. Table 1 presents the criteria and weight for the deliverable of this milestone.

Table 1. Assessment criteria and weight of each for deliverable of milestone 3.

Criteria	Weight
Preparation and creativity	15%
Content exploration	15%
Presentation and delivery	25%
Demonstration and simulation	25%
Results and discussion	15%
Submission of all materials on time	5%

This challenging project not only provided a valuable practical experience but also brought tangible benefits to the analysed company, reinforcing the importance of applying PSO concepts to solve real-world industrial problems. A summary of the weight of each assessment component for the course, including the project and

the quizzes, is presented in Table 2, which outlines how each element contributes to the final grade of the course.

Table 2. Weight of assessment components.

Assessment components	Weight
3 Individual Quizzes	30% (10% each)
Project (Milestone 1 + Milestone 2 + Milestone 3)	70% (25% + 15% + 30%)

3 Project development and hands-on simulation activity preparation

To achieve this project, a team was formed consisting of seven female students (the authors of this paper) and one male student, who was a working student and not enrolled on a full-time basis. All team members had previously collaborated in other courses and academic years, which facilitated group dynamics and project coordination.

At the outset of the project, the team decided to collaborate with a real company rather than construct a hypothetical case. The primary motivation was to gain a more practical and applied understanding of industrial processes, rather than relying solely on theoretical assumptions. By engaging with an existing company, the team aimed to immerse in a tangible manufacturing environment, confronting real-world constraints and operational challenges. This approach allowed the team to observe first-hand the intricacies of production workflows, resource management, and decision-making processes, providing a depth of learning that a fictional scenario could not offer.

3.1 Company selection, contact and visits

To identify a suitable enterprise for the study, the team conducted extensive research on companies operating in the vicinity of the university. While many of the potential candidates were textile manufacturers - given the predominance of this industry in the region - the team also explored alternatives in different sectors. The considered enterprises specialized in footwear production, prefabricated housing, and other manufacturing domains. The team goal was to find a company that would be both accessible and open to collaboration. After narrowing down the options, the team reached out to several enterprises, initiating communication to assess their willingness to participate in our project.

Establishing contact with enterprises proved to be a challenging process, as obtaining responses required persistent effort. The team initiated multiple outreach attempts, and after considerable effort, the team successfully established a connection with one enterprise due to a group member's acquaintance within the company. Coincidentally, around the same time, the team also received a positive response from another enterprise. Given this unexpected opportunity, the team decided to divide and conduct visits to both companies. These visits were crucial in refining understanding of the production environment and collecting relevant data.

Prior to the visits, the team meticulously prepared a list of key questions to ensure that the team gathered comprehensive information on manufacturing processes, equipment usage, and workflow dynamics. By engaging with employees and supervisors on-site, the team gained valuable insights into the daily operations and challenges faced by each enterprise. After careful consideration, the team chose to proceed with the company that demonstrated the greatest openness to collaboration and willingness to share relevant information. The team expressed our gratitude to the other company for their time and support, acknowledging the valuable insights gained from the visit.

Following our initial visit, the team continued engaged with the selected company by maintaining open communication via email. As the research progressed, new questions and areas of interest emerged, prompting to reach out for further clarifications. The company was receptive to inquiries, providing additional insights that enriched the understanding of the production process. Recognizing the importance of first-hand observation, the team arranged a second site visit with the entire group.

During this visit (Figure 1), the team focused on mapping the factory floor layout and resolving outstanding queries. The team had the opportunity to interact with an engineer overseeing the production section, who provided a more detailed explanation of the workflow. This deeper engagement allowed the observation of the machines in operation, enhancing the comprehension of the production dynamics and reinforcing the relevance of the study.



Figure 1. Visit to the company.

3.2 Selection and critical analysis of the study sector

Given the large dimensions of the selected company, the team decided to focus on the reconfiguration of the dyeing sector, as it would be unfeasible to analyse the entire factory within the limited project time frame, which was three months. This decision was supported by the fact that the engineer responsible for the guided tour mentioned that this sector presented the highest waste, both in terms of time and in terms of other operational aspects.

Therefore, to understand the current conditions of the company and identify potential issues, the team carried out various analyses, which the team learn in class and applied to the real context. Thus, the team started by classifying the production system according to quantity, layout, demand satisfaction mode, nature of products, and nature of material flow (Alves, 2016).

To better understand the production process, the team conducted a product-quantity (P-Q) analysis, as the company manufactures various types of sheets, resulting in the production of different types of rolls. However, due to the project's time limitations, the team chose to focus only on the rolls corresponding to the most demanded products, which were cotton rolls followed by linen rolls.

Next, the team developed a SIPOC diagram for the dyeing section to identify the suppliers, inputs, processes, outputs, and customers of this specific unit (George et al., 2005). This was followed by a mapping of the workflow for the products under analysis, which allowed us to understand the sequence of machines each roll passed through within the section, providing a clear view of the production sequence. At this stage, it was crucial to analyse all activities for each product, distinguishing between value-added (VA) and non-value-added (NVA) activities. To gain a clearer view of the entire process, the team developed the current layout of the section using AutoCAD, accurately representing all machines, corridors, and storage areas to a 1:1000 scale.

Additionally, the team traced the path of the rolls in the current layout and calculated the distances travelled by each of them. To better understand the company's situation, the team analysed performance measures such

as takt time, cycle time, work in process, among others, which allowed us to quantify critical operational aspects and identify possible improvements.

3.3 Production system reconfiguration phase

After analysing and understanding the company's initial conditions, it was possible to proceed to the system reconfiguration phase. During this process, the team identified that the system in place at the company was functional, also known as a workshop system, and proceeded to transform it into an operational cell with the Baton-Touch operating mode. The Baton-Touch mode was employed, where each participant was responsible for a specific task in the production chain, passing on the responsibility to the next team member, mimicking a real-world production line (Baudin, 2003).

At this stage, the team defined a set of balancing objectives, such as to reduce the number of workstations and cycle time (increasing production rate), increasing efficiency while considering operational and production constraints, increasing profits (difference between revenue and costs), and reducing costs. To achieve these objectives, the team applied the Wild method for balancing by grouping products with similar production steps, using aggregated load to then organize them efficiently into workstations, ensuring an improved production flow and waste reduction (Alves, 2024).

Next, the team created a relationship diagram, focused not on the relationship between sections, but rather between machines, which led us to develop two layout proposals (Figure 2). After the new design, the team once again used AutoCAD to calculate the distances travelled by each roll, which resulted in two solutions where the distances for linen rolls increased, which was considered normal, as the focus was more on the cotton roll path due to its higher demand.



Figure 2. Layout proposals to reduce distances (in Portuguese).

In both solutions, the team managed to reduce more than half of the distance travelled by the cotton rolls. In the end, the team chose the layout that, although it had a higher total distance travelled by both rolls, offered the shortest distance for the cotton roll. With the new layout, the team achieved a total reduction of about 95.6 meters in the distance travelled for the production of one cotton roll and one linen roll.

The proposal to implement a new production layout aims to reorganize the workflow in a more continuous and efficient way. Among the main advantages are the creation of a more organized production flow, the elimination of unnecessary activities, and the better use of available human potential. These factors contribute significantly to the increase in the company's productive efficiency, resulting, in the medium and long term, in lower operational costs.

However, the proposal also presents disadvantages that must be carefully considered. The movement and reorganization of machines, along with the necessary reconfiguration of the physical layout, involve a high initial cost. Additionally, it will be essential to provide training for operators, which represents another investment, the cost of training workers. These factors may have a financial impact in the short term, although significant operational benefits are expected in the future.

3.4 Lessons learned: theoretical vs real setting

Throughout the development and design of the layouts, the team applied the theoretical concepts acquired during the lessons in the course. However, the team quickly realized that it was not enough to strictly follow the methods. The company's reality presented a series of limitations and challenges that needed to be considered. Among the main constraints were physical limitations of the facilities, such as the available space and machine layout, as well as economic issues related to costs and the feasibility of the proposed changes. Additionally, operational factors, such as machine production capacity and material flow dynamics, also influenced the layout solutions. The practical experience within the company was essential, as it allowed us to understand how industrial engineering managers deal with these constraints on a daily basis, adjusting theoretical concepts to the complexity and specifics of the production environment.

3.5 Hands-on simulation preparation

The next phase of the project focused on translating the observations into a functional and physical simulation model. This stage required creativity, teamwork, and a high degree of responsibility, as the team aimed to construct a model that effectively demonstrated the production process in a simplified yet accurate manner.

The team selected key machines representative of the manufacturing process, including a gas-fired machine, a washing machine using caustic soda, a drying and ironing machine, and a foulard. To construct the simulation, the team utilized materials such as recycled cardboard boxes, kitchen paper rolls, scissors, paints, hot glue, markers, adhesive tape, and brushes. These materials enabled the creation of a tangible representation of the production sequence, allowing to analyse workflow efficiency and potential areas for improvement.

The project involved several trials and adjustments, as the team worked collectively to refine the accuracy and clarity of the model. In total, ten different simulation attempts were carried out to achieve the most accurate possible representation of the operating mode, ensuring that the baton-touch workflow was effectively conveyed. Furthermore, the team conducted multiple rehearsals to ensure that the presentation accurately reflected the real-world dynamics observed in the factory. This experience was both challenging and rewarding, as it allowed us to transform industrial complexity into a comprehensible visual format, reinforcing our understanding of the production environment and strengthening our ability to work collaboratively under pressure. In the hands-on simulation, the team specifically examined production processes for two types of textile products. By incorporating real-world parameters observed during the site visits, the team aimed to replicate the conditions and constraints encountered in the industry. The hands-on experience of developing and refining the simulation model reinforced the understanding of industrial operations, bridging the gap between theoretical knowledge and practical application.

4 Results and discussion

The hands-on simulation played a key role in consolidating the team's understanding of the reconfigured production system and communicating it effectively to an academic audience. Developing the model required not only technical precision but also a high degree of adaptability, as the team aimed to balance simplification with realism. Over the course of the preparation, ten different configurations were tested and refined to ensure the most accurate and pedagogically effective representation of the manufacturing process using the baton-touch mode.

This iterative effort promoted collaborative problem-solving and highlighted the importance of teamwork in addressing practical challenges. By translating industrial complexity into a clear and engaging visual format, the team created a model that supported both learning and dissemination. Furthermore, the commitment to

active learning was evident throughout, from the decision to collaborate with a real company to the design and execution of the simulation.

As one team member highlighted:

"It is important to highlight that this project allowed me to truly experience the value of active learning, as it challenged me to take initiative, work collaboratively, and apply theoretical knowledge to real industrial problems, thereby strengthening my technical skills and preparing me for future professional challenges."

The entire process contributed significantly to the development of transversal competencies such as critical thinking, communication, and adaptability - skills that are essential for future professional practice in industrial engineering. For the presentation of this project, the team developed a scaled-down simulation, which was presented to the class. In this simulation, cardboard boxes were used to represent the various machines in the factory, such as the gassing machine, fabric washing and drying machines, among others. Additionally, kitchen paper rolls were used to simulate the fabric rolls (Figure 3).

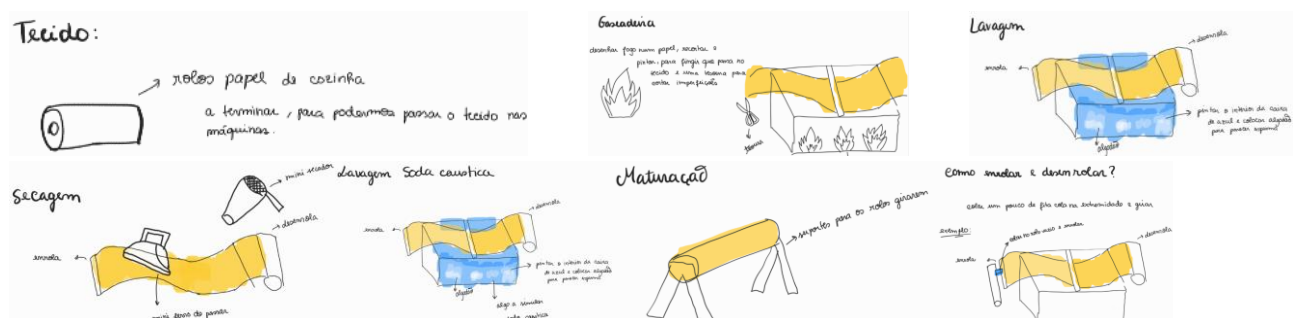


Figure 3. The simulation of the process using practical and accessible materials and tools to represent the real process (in Portuguese).

Based on this sketch, the boxes were cut and labelled with the names of the respective machines, thus facilitating the understanding of the simulation by the observers. The boxes (representing the machines) were arranged on tables in the classroom, and each team member was assigned responsibility for one or two specific processes. During the simulation, the team members manually unrolled and rolled the paper rolls, simulating their passage through the corresponding machines.

To further support the classmates' understanding, everyday household items were used, such as a hairdryer (to simulate fabric drying) and an iron (to simulate the ironing process). Although these props do not accurately replicate the industrial procedures, the team believed they would help to clarify the process more clearly.

While the team was generally satisfied with the outcome of the simulation, it is important to note that not everything went as expected, particularly when compared to previous rehearsals. As this was a live presentation, it was essential that the narration of the processes - carried out by one team member - was synchronised with the actions performed by the others. However, factors such as potential nervousness, the inclusion of micro-processes (e.g., machine programming), or unforeseen issues (e.g., the fabric rolls getting stuck or being difficult to roll) occasionally led to a mismatch between the narration and the demonstration, requiring adjustments to the pacing.

Despite these challenges, the team believes that the simulation successfully achieved its main objective: to effectively convey the concept of a factory floor and the sequence of processes involved.

As one team member reflected:

"More than the presentation itself, the real challenge lay in the ability to accurately and clearly translate the dynamics of a factory environment, particularly regarding the implementation of the baton-touch mode."

One additional challenge was the arrangement of the machines. In order to ensure visibility for the entire class, it was not possible to replicate the exact layout used in the factory (as seen in Baton Touch). Instead, a layout was adopted that prioritised clarity and visibility for the audience. Figure 4 presents some photos taken during the classroom presentation conducted by the team.



Figure 4. Classroom presentation.

5 Conclusion

This paper presents a team perspective of a hands-on activity simulated in the classroom to represent the reconfiguration and improvement of a company's production system. Developed within the scope of the Production Systems Organization course, this project offered students the opportunity to apply theoretical concepts in a real industrial context, specifically focusing on the dyeing section of a textile company selected for its operational relevance and complexity.

Throughout the project, students applied a range of production analysis tools - such as P-Q analysis, SIPOC diagrams, spaghetti and layout mapping, value-added and non-value-added analysis, and balancing techniques. These tools enabled a systematic diagnosis of the current state and supported the design of a reconfigured system aligned with Lean Thinking principles (Womack & Jones, 1996). The transformation from a functional layout to a cellular production system, using the Baton-Touch operating mode, resulted in significant performance improvements, most notably a reduction of approximately 96 meters in the overall material flow for the company's most critical product line.

The autonomy granted to the team in selecting both the type of product and the partner company stimulated proactivity, responsibility, and strategic decision-making. This flexibility provided a deeper understanding of the challenges and dynamics of the industrial environment that the team is likely to face in the near future. By engaging with real-world situations, students were exposed to contexts that required adaptability, critical thinking, and the capacity to solve complex problems - competencies that are highly valued in today's job market. Moreover, contacting and collaborating with real companies enabled the development of essential soft skills, including communication, negotiation, and project management, all of which contribute directly to future professional readiness.

The pedagogical value of this experience lies in its ability to bridge the gap between theoretical instruction and practical application. By interacting directly with an industrial partner, conducting on-site visits, and navigating real operational constraints - such as space limitations, resource availability, and workflow complexity - students gained a deeper, more authentic understanding of industrial dynamics. The project demanded not only technical proficiency but also flexibility, creativity, and perseverance in problem-solving.

Furthermore, the development and presentation of a physical simulation model using accessible materials contributed to experiential learning and peer education. It facilitated the visualization of production processes

and helped communicate proposed improvements to an academic audience. Although minor challenges arose during the live demonstration, such as synchronizing actions and adapting layout visibility for the classroom setting, the simulation successfully conveyed the essence of the redesigned system.

In conclusion, this project demonstrated the effectiveness of integrating real-world challenges and active learning methodologies into engineering education. It provided a holistic learning experience that complemented theoretical knowledge with practical insight, preparing students more effectively for the complexity and multidimensionality of modern production systems.

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From Classroom to the Industry: PBL in Action from the point of view of a team of students

Ana Carolina Cunha¹, Ana Catarina Abreu¹, Ana Luísa Machado¹, Bárbara Silva¹, Carolina Dantas¹, Catarina Wilson¹, Inês Araújo¹, Lara Correia¹, Raquel Dantas¹, Rui M. Lima¹

¹ ALGORITMI Centre, Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal

Email: carolinacunha423@gmail.com, catarinarmabreu@gmail.com, aluisadsm@gmail.com, barbarasilva220203@gmail.com, carolinadantas8@gmail.com, catarina.gomes.wilson@gmail.com, inesaraujo422@gmail.com, larafranciscacccc@gmail.com, dantascraquel2002@gmail.com, rml@dps.uminho.pt

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Abstract

Active learning encourages students to actively engage in the classroom rather than passively receiving information from lectures. Over the past decade, universities have increasingly adopted active learning, proving its effectiveness in enhancing student outcomes. In the Master's Degree in Industrial Engineering and Management at the University of Minho, students are encouraged to work in collaborative groups to solve real complex problems. This approach is implemented in the Integrated Project in Industrial Engineering and Management course, which implements Project-Based Learning (PBL). Through PBL, students engage directly with companies to address real-world challenges, fostering University-Business Cooperation. This methodology provides an exceptional opportunity for engineering students to develop critical competences demanded by the professional world, including project management competences, bridging the gap between the learning process and industry practice. Moreover, the opportunity arose to integrate the project into an international and more sustainable dimension through the ERASMUS+ EGALITARIAN project, aiming to raise awareness within the company about its environmental footprint. The main objective of this article is to characterise the development of competences and the application of knowledge acquired throughout the academic journey, from the eyes of a team of students developing the project. Moreover, the article aims to describe the agile project management approach implemented by this team, which may be a valuable example for other students working in PBL. The experience proved to be highly enriching, offering students the opportunity to strengthen critical competences such as problem-solving, teamwork and project management. Additionally, participants enhanced their ability to communicate effectively with stakeholders, think critically under pressure and adapt to industrial challenges, while also developing valuable competences in areas such as sustainability assessment and environmental impact analysis. As part of the ERASMUS+ EGALITARIAN program, the project combined cross-cultural collaboration focusing on sustainable practices and fostering environmental responsibility among future leaders in engineering and management.

Keywords: Project-Based Learning; University-Business Cooperation; Industrial Engineering and Management.

1 Introduction

Active learning methods have proven to be effective in improving engineering self-efficacy, academic performance and students' sense of responsibility in completing future tasks (Major & Kirn, 2017). These learning approaches include problem-based learning (PBL), case studies, group projects, simulations and other collaborative activities that encourage students to take an active role in their learning (Jaroenphasemmesuk et al., 2023). Within this framework, PBL enables students to develop competencies by engaging in project work that addresses real-world problems (Lima et al., 2017).

Furthermore, research indicates that active learning approaches, such as PBL, are significantly more effective (Freeman et al., 2014; Theobald et al., 2020) than traditional direct instruction in promoting student learning outcomes. Notably, PBL has been shown to enhance students' engineering self-efficacy, a factor strongly correlated with student performance in engineering education. If similar results are observed for engineering design self-efficacy and PBL, it is expected that students' willingness to engage in learning and design activities

will increase through the implementation of active learning strategies into engineering programs (Major & Kirn, 2016).

The development of projects in industrial context constitutes an exceptional opportunity for engineering students to develop competences expected by the labour market (Lima et al., 2017).

According to Alves et al. (2016), teachers have identified PBL as a positive learning approach that enhances student motivation, engagement and comprehension of the practical applications of theoretical concepts. Additionally, research has explored the role of teachers and their perceptions of PBL (Habók & Nagy, 2016; Han et al., 2015) and shows that integrating them into a university-industry collaboration framework offers further advantages in addition to the benefits of active learning methods. Students demonstrate higher levels of engagement and motivation when working on real-world problems proposed by companies. Additionally, this approach creates an enriched learning environment that closely simulates the conditions and challenges they will encounter in their professional careers (Jaca et al., 2021). However, there is a lack of studies examining PBL from the students' perspective.

This study was conducted at University of Minho, a public university in northern Portugal, with first-year Master's students in Industrial Management and Engineering during the first semester of the 2024/2025 academic year. It took place within a project-based course that adopts an interdisciplinary PBL approach in collaboration with industrial companies. Furthermore, some students took part in ERASMUS+ EGALITARIAN project, a student-led initiative that unites individuals from diverse backgrounds to develop innovative solutions for improving waste management and supporting waste pickers in Brasília, in line with the goals of the 2030 Agenda. Each semester, the initiative fosters new projects aimed at creating a meaningful impact (*Egalitarian*, 2025). For the Portugal Students, the challenge was to explore methodologies to estimate the carbon footprint of two Portuguese companies, assessing their environmental impact and proposing actionable strategies for mitigation.

This paper aims to address the lack of studies examining PBL initiatives from the students' perspective, particularly within corporate environments. It analyses the experiences of a student team, focusing on the challenges, difficulties and motivational factors they encountered, as well as how competences acquired throughout their academic journey were applied in practice. The study also highlights the agile project management approach adopted by the team. By offering these insights, this work contributes to a better understanding of how academic skills are integrated into real-world, corporate-driven projects.

2 Project Description

The PBL approach discussed in this paper is implemented during the first semester of the Master's Degree in Industrial Engineering and Management at the University of Minho, specifically in the Integrated Project in Industrial Engineering and Management course. Students at the University of Minho benefit from an institution at the forefront of practical teaching methodologies, having implemented these approaches since 2005 (Lima et al., 2017). This approach immerses students in real-world challenges, offering them the opportunity to tackle practical problems faced by companies across various industries. By working directly within an industrial context, students are encouraged to develop solutions for real-world issues, thereby enhancing both their technical and transversal competences (Lima et al., 2017). The university partners with companies from a wide range of sectors, including construction, energy, textiles and sanitation, providing students with valuable hands-on experience across diverse business environments.

Throughout the project, students benefit from the integration of key concepts from five other courses within the same semester. These courses include Advanced Production Systems Organization, Ergonomics and

Human Factors, Industrial Project Management and Process Modelling and Analysis. Each course plays a crucial role in equipping students to address various aspects of the project, strengthening their practical and theoretical understanding. Teachers responsible for these courses provide continuous support throughout the project's execution, ensuring that students can effectively apply the engineering concepts learned (Lima et al., 2017). The overall project approach encourages the seamless integration of multiple disciplines, fostering collaboration between students, the university and external industry partners. This enriches the students' experience and better prepares them for real-world challenges.

The project is carried out by teams of 7 to 9 students, each assigned to one of the 7 pre-selected companies by the university. These teams collaborate closely with their assigned company, addressing real-world challenges within the company's operational environment (Lima et al., 2017). The problems to be tackled must be simultaneously aligned with the specific needs and priorities of the companies and the boundaries set by the courses' content and learning outcomes. Since this course lasts for only one semester, teams have a four-month window to complete the project, requiring them to manage tasks and deliverables efficiently within a limited timeframe.

To gather relevant data and insights, the team conducts weekly visits to the company, including trips to the shop floor to observe processes and collect firsthand information. During these visits, students meet with company mentors to discuss progress and receive guidance. Additionally, there is a designated day each week solely dedicated to the project, providing time for meetings with teachers and independent work.

The project unfolds in two main phases. Initially, students focus on understanding the company's current state by conducting a thorough diagnostic phase. This involves analyzing processes, identifying inefficiencies and mapping out key challenges within the production system. Once a clear understanding of the existing conditions is established, teams transition to the second phase, developing targeted improvement proposals to address the identified issues (Lima et al., 2017).

Effectively managing a project of this complexity requires a structured approach to ensure teams stay aligned with their objectives and deadlines. Given the short timeframe and the multiple stakeholders involved, students rely on agile project management tools and techniques to plan, coordinate and track progress efficiently.

2.1 Project development

This project was developed in a Portuguese company specialized in off-site bathroom construction, providing faster, simpler and more cost-effective solutions. This company highlighted the need to overcome certain issues within the production system, including unbalanced workstations, a non-linear material flow and poorly defined workstation locations. Additionally, it emphasizes the importance of establishing a line-side delivery system to ensure the efficient and consistent supply of materials to all workstations. Furthermore, integrating human capital into the final solution is crucial to ensure that improvement proposals go beyond the workplace, prioritizing the well-being and engagement of employees. Lastly, as part of the ERASMUS+ EGALITARIAN project, the team was also challenged to quantify the company's carbon footprint, including CO₂ emissions from solid waste. This assessment helps the company better understand its environmental impact and take informed actions to reduce it (Barua et al., 2020).

2.1.1 The need to improve production flow

The current factory layout for manufacturing modular sanitary installations (PODs) faced inefficiencies such as unbalanced workstations, non-linear material flow and poorly defined workstation locations, causing delays, inconsistent material availability and missed production targets (Mahto & Kumar, 2013). Lean methodologies, including takt time, precedence diagrams and line balancing techniques, were applied but proved unfeasible due to space constraints. This restriction led to a collaborative effort with the company to identify simultaneous

tasks inside and outside the POD. The new in-line layout, with continuous flow and a conveyor system, improved synchronization, reduced transport interruptions and waiting times and eliminated forklift use. These changes offered students hands-on experience in Lean Manufacturing and problem-solving.

2.1.2 The need to improve internal logistics activities

The implementation of an efficient internal logistics flow in modular production ensures material availability at the right time without excess stock or waste (Coimbra, 2009). Three replenishment methods were adopted: Mizusumashi (manual cart with 4 or 6 daily cycles), Kanban for bulky and time-sensitive materials, and periodic replenishment for predictable items. Ergonomic analysis confirmed both Mizusumashi cycles as safe (Gotthardt et al., 2019), with the 4-cycle option offering better time efficiency. A visual management system, with boards and luminous signals, enhances stock control, reduces errors and ensures that only necessary materials are transported in each cycle. Despite space constraints caused by the conveyor belt, storage was strategically positioned to optimize flow. This integrated approach balanced material availability, operator safety, and logistical efficiency, meeting the factory's operational needs.

2.1.3 The need to integrate human capital

Organizational systems face constant changes and human capital's adaptability is the key to maintain resilience and achieve goals (Picaró et al., 2016). To understand people as interconnected parts within a work system, a systemic approach was adopted. This approach recognizes the organization as an interdependent system, where human, structural and technological factors directly influence the outcomes, enabling more effective strategic decisions and increasing organizational resilience.

Applying this approach revealed several critical issues. The company has a high turnover rate of 18% and Body Mass Index data highlighted individual health concerns. Moreover, all work instructions, procedures and training are provided solely in Portuguese, creating barriers for non-native speakers. Although the number of accidents is low, external factors were found to contribute to their occurrence.

To address these issues, the team proposed employee recognition and stronger manager-worker relationships to reduce turnover, as well as targeted training to boost satisfaction and retention. Instructions should be provided in a universal language or pictograms, with periodic comprehension assessments. To address Body Mass Index concerns, the canteen should offer tailored meals, supported by awareness campaigns. Additionally, all accident causes, including near misses, should be thoroughly analysed to improve safety.

2.1.4 The need to quantify the carbon footprint

The project addressed the challenge of estimating the company's carbon footprint, a value never previously calculated. This involved a detailed assessment of environmental impacts, covering waste management, energy and water consumption and the development of tools to quantify carbon emissions. Collaboration within the ERASMUS+ EGALITARIAN program, especially with a Brazilian team, was essential to map emission sources across the three scopes and enrich the approach through knowledge exchange.

To estimate the company's CO₂ emissions, emission factors were applied to all activities related to the production, delivery of PODs and treatment of solid waste, considering its end-of-life impact. A carbon footprint calculator was also automated, allowing the company to input data easily and obtain reliable results. Additionally, the tool estimates the number of trees needed to offset emissions and guides the company toward carbon neutrality.

More than a calculation tool, this initiative aims to raise environmental awareness within the organization, supporting informed, sustainable decision-making and concrete steps toward reducing its carbon footprint.

2.2 Project management

Project management is the planning, organization, monitoring and control of all aspects of a project, while motivating all involved to achieve its goals safely, within the agreed schedule, budget and performance criteria (IPMA (International Project Management Association), 2006). It encompasses various methodologies, each designed to enhance efficiency and structure within a project. Among these, the Project Model Canvas is a project management tool that provides a comprehensive overview of all key aspects, including objectives, stakeholders and project stages. Inspired by the Business Model Generation, it simplifies project planning by using a visual and intuitive approach, reducing bureaucracy and facilitating quick decision-making (Silva & Cardoso, 2019).

The Project Model Canvas served as a true guiding thread for the team, providing a clear and structured framework for the project's development. Its centralized visualization made it easier to identify potential limitations and challenges, enabling a more proactive and efficient management approach. As a result, the team remained aligned and adapted to project needs and made more informed decisions throughout the process.

As the project progressed, it became clear that the tool needed adjustments to align with the emerging objectives. Consequently, it was necessary to make some changes to the initial version of this document in order to more accurately reflect the current reality of the project. One critical aspect that was initially overlooked but proved to be essential was the potential interruption of production at the factory. This unexpected constraint caused significant delays, highlighting the importance of anticipating such risks from the early planning stages to mitigate their impact and ensure better timeline management.

The SCRUM framework is widely recognized as one of the most implemented approaches within agile project management (Lei et al., 2017). This methodology supports collaborative efforts among team members by dividing their work into manageable tasks that are designed to be completed during fixed-length cycles known as "sprints" (Hidalgo, 2019). Through regular meetings, the team monitors their progress and adjusts plans as necessary, enabling the incremental development of products.

During the project's development, SCRUM artifacts were implemented to ensure efficient management aligned with its objectives. Defining roles was crucial to the process's success: the Product Owners represented the company's interests, the SCRUM Master facilitated the workflow and helped overcome obstacles and the development team executed tasks, turning ideas into results. At the end of each sprint, a Sprint Review Meeting was held to assess completed work and adjust future plans.

To provide clear progress tracking, the team implemented a Kanban Board, enabling the visualization of ongoing, completed and pending tasks, which facilitates continuous monitoring and efficient project management. Weekly sprints were conducted, starting with Sprint Planning Meetings to define tasks, assign responsibilities and estimate effort using the Planning Poker technique. Additionally, in Daily Scrums, the team communicates progress and upcoming tasks, allowing the SCRUM Master to update the Kanban Board as work progresses.

Leveraging the Kanban Board, the team also developed a Burndown Chart to monitor task completion rates and adjust actions as needed, ensuring the project remains on schedule. These artifacts not only structured the workflow but also provided flexibility and visibility, allowing the team to adapt to emerging challenges effectively.

3 What about the experience?

The participation in this project represented a significant milestone for our team, marking our first direct experience with the industry. Throughout the project, we faced a variety of challenges that tested our ability to adapt, collaborate and find innovative solutions under real-world constraints. This experience enriched our academic journey and contributed significantly to our professional and personal development.

3.1 Understanding each other

Right from the beginning, we recognised the importance of understanding the individual characteristics of each team member, which led us to conduct personality and work-style assessments before starting the project. This initiative allowed us to anticipate potential dynamics and make the most of each member's strengths, ensuring a productive and collaborative environment. In this initial phase, we used the MBTI (Myers-Briggs Type Indicator) test to identify the main personality types within the group, which included Analysts, Sentinels, Diplomats and Explorers. This diversity was key to balancing perspectives and working styles. Additionally, the Belbin Team Roles test helped us understand how each person naturally contributes to a team setting, identifying profiles such as Monitor Evaluator, Implementer and Teamworker. These tools enabled us to strategically form subgroups with complementary strengths. A clear example was the subgroup formed by three team members with highly analytical, structured and leadership-oriented profiles, combining a focus on strategic vision, organization and decision-making under pressure. In this trio, their Belbin profiles (Completer Finisher, Implementer and Monitor Evaluator) worked in perfect synergy, ensuring that ideas were implemented efficiently, with rigorous quality control and constant monitoring of project objectives. This approach directly impacted the success and resilience of the project, especially in high-pressure situations. This allowed the members to know each other better, which naturally strengthened trust, communication and group cohesion. This familiarity made it easier to anticipate reactions, distribute tasks intuitively and maintain a positive and highly supportive working atmosphere. It allowed us to form not just a good team, but an exceptional one, where collaboration was seamless and motivation came naturally.

3.2 Dealing with unexpected events

One of the most demanding moments occurred when the company shifted its focus to a different project, leading to a temporary halt in production. At that point, our team had already conducted a thorough diagnostic analysis, only to realise that we had to restart this phase within a much shorter timeframe. This imposed an additional layer of complexity, requiring us to be more agile, prioritize tasks effectively and make data-driven decisions more efficiently. However, what could have been a setback was transformed into a key moment of growth thanks to our structured teamwork, deep knowledge of one another's working styles and the resilience we had developed. We quickly reorganised ourselves, relying on the strengths of each profile and using our well-established subgroups to respond rapidly and effectively. Therefore, this situation ultimately turned into an opportunity to refine our analytical skills, enhance our problem-solving abilities and improve our ability to work under pressure.

Another significant challenge arose when our initial company mentor left the organization midway through the project. The transition to a new mentor presented some initial difficulties, as we had to quickly adapt to a different leadership style and reestablish a working dynamic. Nevertheless, we were able to navigate the transition effectively, ensuring the project moved forward with clarity and purpose. We were fortunate to receive consistent support, not only from our new mentor, who quickly integrated into the project and offered valuable guidance, but also from the company itself. Their ongoing encouragement and the clear recognition of the value of our work played a fundamental role in our motivation. Knowing that our efforts were appreciated and that our contributions had a real impact was incredibly rewarding. This sense of acknowledgement became

a driving force that pushed us to improve and give our very best continuously. This experience was not only a test of our adaptability and resilience, but also a powerful reminder of the importance of supportive leadership and a positive organizational culture in overcoming challenges.

Moreover, our collaboration with a specialized organization in continuous improvement provided valuable insights into efficiency and innovation approaches. The exchange of knowledge with industry professionals allowed us to broaden our understanding of the problem from a new perspective, adding value to our work and strengthening our proposed solutions.

3.3 International collaboration

The integration of the ERASMUS+ Egalitarian project was a transformative experience for our team, particularly due to its focus on sustainability. A key contribution was the calculation of the company's carbon footprint, which allowed us to identify areas for improvement and implement more environmentally conscious practices. This analysis not only aligned with our technical goals but also deepened our understanding of sustainable engineering. This multicultural and interdisciplinary collaboration allowed for a broader perspective, integrating diverse approaches to enhance both efficiency and sustainability. The exchange of knowledge and methodologies from different academic backgrounds contributed to the development of more inclusive, adaptable and socially responsible engineering solutions. Beyond the technical benefits, participating in an ERASMUS+ project brought invaluable advantages. It facilitated knowledge exchange with international teams, exposing us to diverse perspectives and innovative approaches. This collaboration strengthened our teamwork, communication and adaptability, as we worked to align Egalitarian principles with our project goals. Furthermore, the experience provided personal and professional growth opportunities for team members, fostering a greater awareness of the social and environmental impacts of engineering. By integrating Egalitarian into our work, we developed solutions that were efficient and aligned with sustainability principles and global responsibility.

3.4 Peer feedback

Beyond the technical and managerial aspects, this project also emphasized the importance of teamwork and self-assessment. Throughout the semester, our team underwent two formal evaluation moments, where we not only received feedback from our professors but also engaged in a peer assessment process. Each member was required to anonymously evaluate contributions, dynamics and overall team performance. The unanimous assignment of equal workload points among all members was a testament to our team's balanced effort distribution and strong collaborative spirit. The feedback we exchanged was overwhelmingly positive, with comments highlighting mutual support, seamless task allocation and a proactive attitude in achieving project goals. Responses emphasized our ability to maintain a constructive working environment, effectively manage conflicts and foster motivation among team members. In particular, one of the responses in the team dynamics evaluation stood out:

"The division of tasks among the team members according to their skills greatly helped the project's development. Everyone adhered to deadlines, ensuring the team met its objectives. Knowing each other well facilitated communication and problem-solving, allowing us to reach agreements quickly by actively listening to each other. Additionally, we always took the opportunity to engage in team-building moments to strengthen relationships and better handle the challenges we encountered." (Team member feedback)

This feedback encapsulates one of the great strengths of our team: our ability to anticipate, adapt and support one another. Because we invested early in understanding how we work, how we think and how we respond under pressure, even the most complex situations were faced with confidence. Problems arose, as they do in

any project, but our cohesion, mutual trust and respect made problem-solving natural and efficient. Difficulties became opportunities to learn, test our resilience and strengthen our collaborative bond.

3.5 Learning results – beyond content

Looking forward, the learnings from this project are highly transferable to other professional and academic contexts. We now understand that successful teamwork is not only about technical competence but also about knowing how to manage different personalities, leadership styles and communication needs. We have learned that adaptability, empathy and a well-balanced distribution of responsibilities, based on each member's natural skills, are key for any team's success. In future projects, we'll carry this experience forward, ensuring that we start by building a solid team foundation, valuing diversity and being aware that not everyone responds in the same way to challenges, leadership or pressure. This awareness will allow us to create even stronger, more resilient and efficient teams, capable of thriving in increasingly complex and multicultural professional environments.

Overall, this project was an invaluable learning experience, offering us a realistic glimpse into industry operations while reinforcing the importance of teamwork, adaptability and continuous learning. The challenges we faced were not mere obstacles but stepping stones – powerful moments of transformation that allowed us to grow both as individuals and as a truly exceptional team. The resilience, collaboration and strategy we demonstrated here will undoubtedly serve as a strong foundation for our future careers, wherever they may lead.

4 Concluding Remarks

This project was more than just an academic exercise; it was an immersive experience in the professional world, where theory and practice converged in a dynamic and challenging way. Rooted in the PBL approach, this initiative provided a hands-on environment where students tackled real-world challenges in collaboration with a company. From the initial contact to the final delivery, every stage was an opportunity for intense learning, filled with challenges, discoveries and personal growth.

Throughout this journey, it became clear that the success of a project is not solely based on technical knowledge but also on adaptability, effective communication and teamwork. Interacting with industry professionals provided us with a privileged insight into market demands, highlighting the importance of skills such as flexibility, problem-solving and expectation management.

Facing unexpected difficulties was part of the process and became one of the greatest sources of learning. The need to align innovative solutions with the company's real needs pushed us to think strategically, experiment different approaches and learn from our mistakes.

Beyond the academic impact, this project reinforced the relevance of collaboration between universities and companies, demonstrating how these partnerships can generate mutual benefits. Students gain valuable practical experience for their future careers, while companies receive creative solutions and fresh perspectives on their challenges.

More than just a curricular assignment, this experience was a concrete step in shaping our professional identity. The bridge between higher education and the job market must continue to be strengthened, as it is through real-world challenges that the professionals of the future are forged.

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Enhancing Digital Learning Accessibility: Usability Testing of the Educado Platform for Waste Pickers' Training

Thaís Luíza R. de Sousas¹, Michele C. Martins¹, Marcelo A.K. Filhos¹, Simone B. S. Monteiro¹, Rodrigo P. Gomes¹, Iara Gomes Andrade¹

¹ Production Engineering, Faculty of Technology, University of Brasilia, Brasilia, Brazil

Email: 170114716@aluno.unb.br; michele.cruz@aluno.unb.br; 170150551@aluno.unb.br; simoneborges@unb.br; rodrpg23@yahoo.com.br; 170012484@aluno.unb.br

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Abstract

The significant increase in the use of digital platforms as study tools has led companies to invest in the quality of applications and websites, aiming to enhance usability. One of the evaluation methods that contribute to quality improvement is usability testing. This method involves direct user interaction with the application, allowing for the identification of issues to eliminate potential failures and deliver a high-performance final product. This article aims to present the results of the usability tests conducted on the Educado app and website; a software platform focused on providing training in different fields of knowledge for waste pickers. The study is conducted within the scope of the Egalitarian project, part of the ERASMUS+ program funded by the European Union, and the Production Project 5 course, which employs an active learning methodology. The research follows a qualitative, exploratory, and applied approach, applying usability testing to four waste pickers from the Recicla Vida cooperative to analyze the app. Additionally, usability tests were conducted with 15 users in total — 11 for the Educado website and 4 for the mobile app, followed by a post-test questionnaire to collect data on the user experience. As a result, the study identified the challenges faced by users, providing insights for further improvements to the Educado software.

Keywords: Egalitarian Project, Educational Platforms, Usability Testing, User Experience, Active Learning.

1 Introduction

Web applications are increasingly integrated into our lives, whether through email tools, social networks, photo and video sharing, and other features. They have become an essential part of our daily lives. With the growing need for mobility and the search for solutions that facilitate remote interaction, the use of collaborative digital platforms has become popular in several segments. People who use mobile devices, whether for work, study, or leisure, prioritize easy access to information in different spatial and temporal contexts, requiring interfaces adapted to the technical and ergonomic limitations of these devices (Drumond and Dias, 2021).

In the educational context, the use of communication and collaboration tools has increased significantly, especially during the height of the pandemic and the consequent need to adapt to Distance Learning (EaD). Distance learning is an important tool for social inclusion, being an option for knowledge to reach all individuals, by making learning times, spaces and content more flexible, without being limited by space and time, offering access to different types of training with quality, approaching the principle of education for all (BOKUMS; MAIA, 2018). With this, the demand for more digital education that allows access to knowledge in the time available to the student, without the need for face-to-face meetings, which would otherwise be impossible due to lack of time or difficulties in transportation.

The Educado software offers free training and qualification courses, helping to expand access to knowledge among vulnerable populations, such as workers in recycling cooperatives. The system consists of two parts: an application, Educado Mobile, which makes courses available for students to take directly from their

smartphones, and a website, Educado Web, where the content creator creates and manages courses, where the courses that will be available on the application are uploaded (MELO, 2024).

Within Brazil, an estimated 281 000 informal waste pickers form one of the country's largest low-income occupational groups, yet their work typically unfolds in fragmented circuits with limited bargaining power and scant access to formal training or public services (BOUVIER, 2021). Purpose-built digital platforms can help close these gaps in three complementary ways. First, mobile learning environments deliver asynchronous, bite-sized lessons that suit the irregular schedules of collectors and overcome the geographic dispersion of cooperatives. Second, evidence from matchmaking apps such as *Cataki* shows that geolocation and in-app messaging can connect pickers directly with households and firms, boosting daily income while challenging the stigma historically attached to the activity. Third, many national and international inclusion programmes now require digital self-registration to unlock social-protection benefits; consequently, intuitive, low-bandwidth interfaces become a prerequisite for full citizenship in emerging formalisation schemes. Accounting for these intertwined learning, market-access, and rights-based dimensions is therefore essential when evaluating the usability of *Educado* from the standpoint of its primary audience.

Through a dynamic and intuitive format, the platform delivers courses that support the development of financial literacy, professional skills, and citizenship awareness among waste pickers. Educado contributes to the empowerment of waste pickers, strengthening their role in promoting a more sustainable and inclusive future, in accordance with the Sustainable Development Goals (SDGs), especially SDG 1, regarding the eradication of poverty, and SDG 4, related to the promotion of quality education (MELO, 2024). The project is being developed by students from the University of Brasília and the University of Aalborg, in Denmark.

According to the ISO/IEC 25010 standard, usability is one of the most important quality attributes, as it is defined as the "ability of the software product to be understood, learned, operated and attractive to the user, when used under specific conditions". According to Nielsen (2010), people increasingly expect better applications; the more the user uses the tools, the more he learns and the fewer errors he tolerates. Usability is presented in the sense of offering better web applications for users, laymen or not, helping in the creation of projects that meet the real needs of the user.

Aligned with this purpose, this article aims to execute and analyze Usability Tests of the Educado application (app) and website, with the purpose of investigating the usability errors of the platform, in order to propose improvements for the development of the application and websites.

2 Theoretical Framework

In this Section, the theoretical basis to support the application of the Usability Tests of this work is presented, and will be subdivided into 3 Subtopics.

2.1 Software Usability

Usability is a crucial aspect of software design and development, as it directly impacts user experience and productivity. Usability, defined as the quality of interaction between users and interfaces, is assessed through empirical tests that identify efficiency, effectiveness, and satisfaction during the execution of specific tasks (Guedes et al., 2023). This feedback is then used to identify usability issues and make improvements to software design. Usability is a multidimensional attribute that integrates qualitative factors such as effectiveness, efficiency, and satisfaction, varying according to the context of use and user characteristics (Santos et al., 2023).

2.2 Milestones – important dates

According to Trendowicz (2023), User Experience (UX) is fundamental in the development of software systems and applications. It focuses on how users interact with a product or service, considering aspects such as usability, accessibility, visual design, and overall user satisfaction. When UX is prioritized by developers, the product has a greater guarantee that it meets users' needs and offers a positive experience. Since UX refers to users' perceptions, emotions, and responses resulting from the use or anticipation of using a product or system.

With this, the ISO 9421 standard defines User Experience as "a person's perception and responses resulting from the use or anticipation of using a product." In other words, UX assessment studies how the user feels after using a product, focusing on the experience, effectiveness, and significant and valuable aspects of using an application. Based on this understanding, it is important to apply Usability Testing, with the aim of testing and consolidating the results. According to Hinderks (2019), "to obtain a good user experience, a product must be easy to learn, efficient to use or well controlled with additional criteria such as aesthetics, pleasure of use, novelty or attractiveness".

2.2.1 Human-Computer Interaction

Human-Computer Interaction (HCI) is an interdisciplinary area focused on improving usability and user experience with computer systems, involving the analysis and design of user interfaces, considering ease of use, efficiency, and satisfaction. HCI research methods consist of usability testing, interviews, and observations, which help identify problems and opportunities for improvement. Applying HCI principles is crucial to creating intuitive and accessible systems, promoting a more natural and efficient interaction between humans and computers.

Within this context, usability testing becomes fundamental, as it allows us to assess whether a system meets quality of use criteria, such as efficiency, effectiveness, and satisfaction (ISO 9241-11, 2018). Such testing involves the direct observation of users interacting with the interface, enabling the identification of problems, barriers, and design improvements. Usability is especially critical in web systems and applications for educational purposes, as it directly impacts the teaching-learning process, student motivation and content retention (Nielsen, 1993).

3 Methodology

This Section presents the methodology used to conduct this study, which was segmented into the Research Method and the Research Structure, with the aim of providing clarity on how the research was conducted.

3.1 Research Method

Since this work aims to perform usability tests on the Educado website and application, with an emphasis on validating the functionalities available on the platforms and their acceptance by end users, the research in this work is of an applied nature, with an exploratory objective, using a qualitative approach.

Applied research seeks to find direct and useful solutions to concrete and immediate issues, which in this study aims to evaluate the Educado website and app. It is dedicated to formulating diagnosis, identifying problems and finding solutions. It responds to a demand formulated by "clients, social actors or institutions" (Gil, 2022, p.48) Exploratory research allows the identification of usage patterns, difficulties encountered by users and areas that need improvement. This type of research can be the starting point for more detailed studies and for the constant improvement of the app and website. According to Gil (2007), this type of research, although apparently simple, explores reality in search of greater knowledge, preparing the ground for subsequent descriptive research.

In qualitative research, unlike the quantitative approach, there is no use of numerical data, as the researcher adopts an inductive approach to describe the observed situation. Consequently, qualitative data cannot be represented graphically. This research is exploratory and investigative in nature. (CRISTIANE 2014; EVÊNCIO et al, 2019).

3.2 Research Structure

The research structure was composed of 4 stages, illustrated in Figure 1.

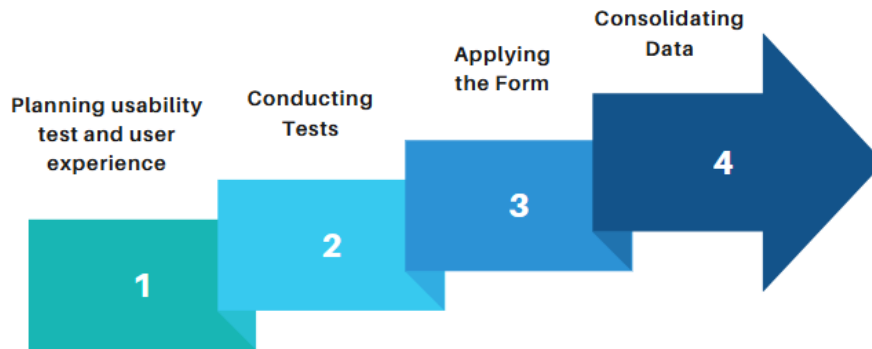


Figure 1 - Stages of Research

As shown in Stage 1, the first stage involves planning the entire usability test on the website and the Educado App. The objective of the usability test was defined, defining the list of activities that the user should perform within the website and the app. In this stage, the user profiles that would be used for the tests were defined. The tests on the Educado App were carried out with 4 recyclable material collectors from the Recicle a Vida cooperative. In the tests on the Educado website, participation was voluntary and had a sample of 11 users with different levels of education. Finally, the post-usability test form was developed based on user experience insights. A total of 15 out of 30 waste pickers were interviewed, representing a 50% sample.

In Stage 2, usability tests of the Educado website and mobile application were conducted on participants' own Android smartphones and on desktop/notebook computers. Each collector completed five predefined tasks in the Educado Mobile app while following a concurrent think-aloud protocol (Cybis, Betion & Faust, 2010). Sessions took place in situ at the Recicla Vida cooperative to preserve ecological validity. Screen activity and audio were captured with AZ Screen Recorder, and a second researcher annotated timestamps and non-verbal cues. The task script—for example, *"enrol in a financial-literacy course and watch the first lesson"*—was piloted with a non-picker to calibrate duration. Informed consent covered audiovisual recording, and each participant received a data voucher to offset connectivity costs. Field notes, screen recordings, and think-aloud transcripts were later triangulated. This stage aimed to map complete user journeys and systematically identify functional bugs and usability problems (UPs), providing a detailed catalogue of pain points for subsequent redesign efforts.

In stage 3, a Post-test Form was applied, with the aim of collecting data on the user experience through structured forms. The data collection, during the questionnaire, resulted in an analysis that highlights the strengths, areas for improvement, and recommendations to improve the user experience of the Educado application and Website.

Finally, all the consolidation and analysis of the results obtained from the form and the users' perception of the Educado website and application were documented in stage 4.

4 Results and Discussions

This Section will present the results of the forms applied in the usability tests of the Educado website and app.

4.1 Usability Test Results on Educado App and Website

4.1.1 User profile

In total, 15 people participated in this research, of which 4 performed the tests on the Educado app and 11 people performed the tests on the Educado website.

To represent the characteristics of the users, graphs were created based on the results obtained through the post-test form. These characteristics are illustrated in the graphs in Figures 2 to 4. The analyses of the characteristics investigated with the test users are presented below.

Age range: 40% of the users are in the age range between 18 and 24 years old. 40% of the users are between 25 and 34 years old. 20% of the users are in the age range between 35 and 45 years old, as shown in Figure 2.

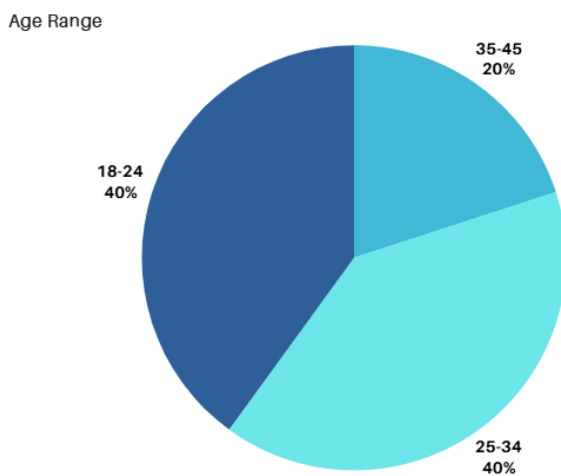


Figure 2. Measuring the age range of the user sample

Level of education: 6.7% of users have incomplete higher education and 26.7% are in progress, while 33.3% of users have completed higher education. 20% of users have incomplete high school education and 6.7% have completed high school education. 6.7% of users have postgraduate degrees, as shown in Figure 3.

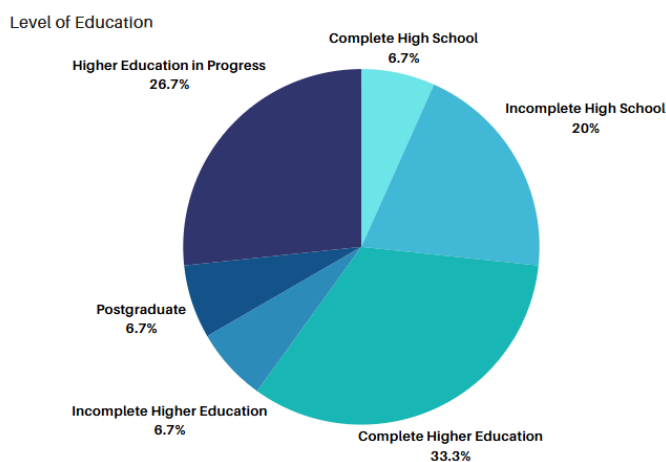


Figure 3. Level of education of the sample of users

Use some platform for educational purposes: 66% (10 out of 15) say they use platforms for educational purposes, 33.3% (5 out of 10) say they do not use platforms for educational purposes, as shown in Figure 4.

Do you use any platforms for educational purposes?

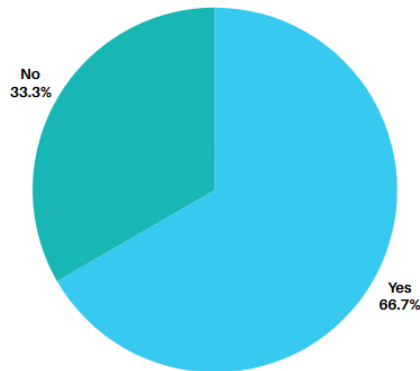


Figure 4. Classification of the use of educational platforms by the sample of users.

4.1.2 Task outline

For the development of usability tests for the app and website, as per Table 1, five activities were mapped to be carried out by users during usability tests on the platforms.

Table 1. Classification of the use of educational platforms by the sample of users

Educado App Activities	Educado Website Activities
Registration Creation	Creating an Account
Accessing a Course	Creating and Editing a Course
Editing a Profile	Accessing Home / Menu
General Opinions about Courses	Login
Accessing the Home Screen	Accessing a Profile

4.1.3 Data collected during the test

When performing usability tests on the website and app, the aim was to identify bugs (defects or failures in the software that cause it to function incorrectly or not as expected) and usability problems (UP), which refer to the difficulty or frustration that users encounter when trying to interact with the application throughout the process of activities performed in the system.

As a result, the errors were counted in each stage of the activity performed on the platforms and the data is presented in Table 2 for the application and in Table 2 for the website. It can be seen that a total of 28 errors were counted for the application and a total of 33 errors were counted for the website, totaling 61 errors on both platforms.

Table 2 shows that the areas of greatest impact on the application are "General Opinions" and "Course", each (7) with 30.4% of total occurrences (23). These steps represent significant areas where users encounter problems or have negative feedback within. They indicate that there are substantial issues with the functionality or usability of the courses offered by the application. This can directly impact satisfaction and the effectiveness of the application for its educational or training purposes.

Table 2. App occurrence stage – Distribution of errors by stage of the Journey

Occurrence Stage	Error type				Total Values	
	BUG		UP		Grand Total	
	Percentage (%)	No. of Errors	Percentage (%)	No. of Errors	Percentage (%)	No. of Errors
Registration Creation	25.00%	1	75.00%	3	100.00%	4
Course	57.14%	4	42.86%	3	100.00%	7
Edit Profile	66.67%	2	33.33%	1	100.00%	3
General Opinions	0%	0	100.00%	7	100.00%	7
Home Screen	100.00%	2	0%	0	100.00%	2
Grand total	39.13%	9	60.87%	14	100.00%	23

Issues in "Registration Creation" are also significant and should be resolved to facilitate the onboarding of new users. Improvements in these areas can have a substantial positive impact on the overall user experience with the application.

Table 3. Website occurrence stage – Distribution of errors by stage of the Journey

Occurrence Stage	Error type				Total Values	
	BUG		UP		Grand Total	
	Percentage (%)	No. of Errors	Percentage (%)	No. of Errors	Percentage (%)	No. of Errors
Account Creation	25.00%	1	75.00%	3	100.00%	4
Creating and Editing a Course	50.00%	3	50.00%	3	100.00%	6
Home / Menu	35.71%	5	64.29%	9	100.00%	14
Login	50.00%	1	50.00%	1	100.00%	2
Profile	42.86%	3	57.14%	4	100.00%	7
Grand total	39.39%	13	60.61%	20	100.00%	33

Table 3 shows the areas of greatest impact on the website. The "Home/Menu" (14) with 42.4% and "Profile" (7) with 21.2% of occurrences are the most critical areas to be addressed to improve navigation and the overall user experience on the website. Issues in "Creating and Editing a Course" show that many users have difficulty creating or editing the courses they have created. This can prevent new users from creating courses and frustrate current users when trying to update their information. In "Account Creation", this step shows that there are significant issues in the process of creating new accounts. This can be a barrier to acquiring new users. Improvements in these areas can have a substantial positive impact on the overall user experience with the website.

4.1.4 User Perception of the Educated App and Website

To collect user opinions, responses from the post-test form were used, which addressed user satisfaction with the usability of the Educado app and website. The form has ten questions, 6 of which are quantitative evaluation

Table 4. User reviews of the Educado website and app

	Educado App Activities	Educado Website Activities
	Average Grade (0 to 10)	
What rating would you give the application?	7.5	6.72
How necessary would it be for your day to day?	8.5	5.45
What grade would you give for appearance ?	8.5	8
What score would you give for the choice of sources?	8	8.63
What grade would you give to the color palettes?	8	8.54
What rating would you give for the app experience?	9	5.81

For the qualitative results, 4 subjective questions were asked, described in Figure 5, in which the user could express their feelings regarding the app and the Educado website.

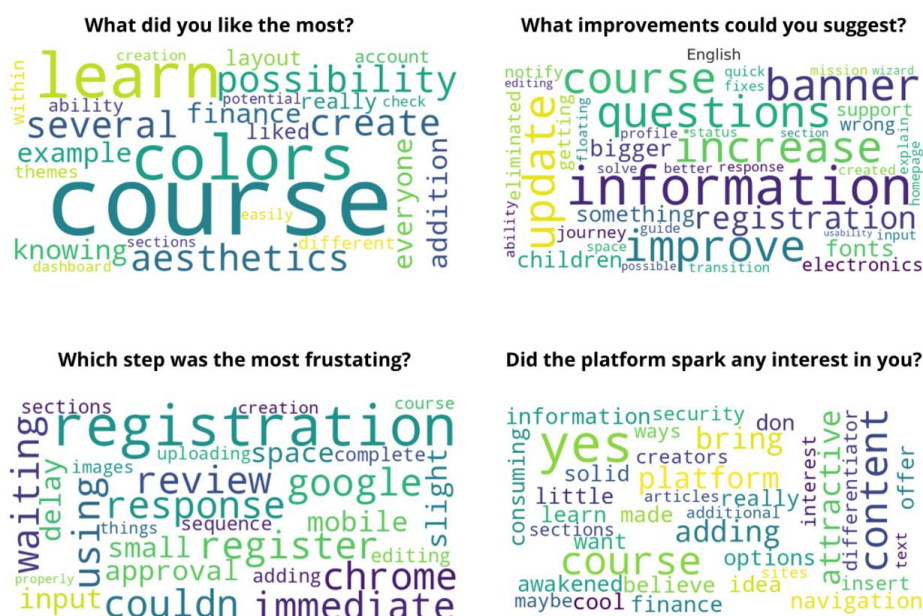


Figure 5. User Perceptions Word Map

From Figure 5, it can be seen that users like the creation features and aesthetic options of the platform, but suggest that improvements are needed, especially in the registration and login process. The word “functionality” suggests that some features are not meeting users’ expectations. Users are suggesting improvements to the platform, specifically the addition of more features or courses. The word “improve” indicates a general desire for improvement, perhaps in usability or in the content available.

5 Conclusion

In summary, the work achieved its main objective of consolidating the survey and prioritization of requirements for the continuous development of the “Educado” app and website. Using usability testing methodologies, market research and statistical analysis, user needs and areas for improvement were identified. The results highlighted the importance of improving the user experience and functionality of the platforms, highlighting significant problems in critical stages such as registration and course creation, for their possible correlation with the aim of promoting a significant improvement in the journey of users of the Educado software.

The applied and exploratory research allowed a deep understanding of the challenges faced by users, providing a solid basis for future improvements. The recommendations derived from user testing and feedback offer a clear path for improving “Educado”, ensuring that future implementations are aligned with user expectations and needs.

Despite the difficulties faced, such as communication with previous developers and delays in updating the status of requirements, the limitation of the interviewee group being small, less than ten, and the fact that they were not the same participants interviewed in the previous phases of the research, although the contributions obtained were relevant to the proposed objectives, it is recognized that the limited sample may restrict the generalization of the results. Added to this is the fact that the app was still in the development phase, presenting several errors and bugs that compromised navigability and made it difficult to properly perform the usability test, the results achieved are promising and the suggested improvements, if implemented, have the potential to significantly increase the satisfaction and effectiveness of the application and website, contributing to greater social and economic inclusion of users.

6 Future Directions

Follow-up research should build on this initial study by broadening the scope and length of user testing. A broader, more diverse sample of waste pickers—and test times that run many times longer than two brief periods—would increase the external validity of the findings and reveal usability issues that only emerge with heavy use. Longitudinal study would then compare actual learning success and engagement patterns to platform metrics (e.g., log-in frequency, course completion) and follow-up surveys or interviews probing for knowledge acquisition, workplace application, and self-assessed effect on quality of life.

Platform evolution, therefore, must remain an iterative cycle of prototyping, field testing, and refinement. Feedback noted above must feed into the subsequent release, after which further user engagement can verify additional features, experiment with interface forms tailored to low-literacy or low-bandwidth contexts, and introduce courses based on evolving community needs. Ongoing participation by waste pickers is necessary for Educado to remain relevant, accessible, and effective.

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International Collaboration in Enhancing Educado: Prioritizing Requirements for an Educational Platform Supporting Waste Pickers in Brasília

Camila de Araújo Valença¹, Giovanna Longo Rocha¹, Iara Gomes Andrade¹, Luíza Andrade Cavalcanti¹, Rodrigo Pereira Gomes¹, Simone Borges Simão Monteiro¹

¹ Production Engineering, Faculty of Technology, University of Brasília, Brasília, Brazil

Email: 202014548@aluno.unb.br, 200074237@aluno.unb.br, 170012484@aluno.unb.br, 202043380@aluno.unb.br, rodrpg23@yahoo.com.br, simone_simao@yahoo.com.br

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Abstract

This article aims to streamline the collection and prioritization of requirements for the ongoing development of the Educado app and website — a platform designed to provide training across various fields of knowledge while fostering social and economic inclusion. By offering accessible and relevant educational materials, Educado seeks to break the cycle of poverty and enhance the quality of life for waste pickers in Brasília. The research follows a qualitative, exploratory, and applied approach, integrating market analysis, the Mudge Matrix for requirement prioritization, and analysis of user feedback previously obtained. It builds on an analysis of the app's previous development cycle within the Egalitarian Emerged project, part of the ERASMUS program funded by European grants. The study encompasses user needs assessment, product improvement identification, and requirement refinement. As a result, 144 structured requirements were defined for implementation in collaboration with students from Aalborg University (Denmark) and the University of Brasília (Brazil). The findings emphasize the significance of structured requirements elicitation and effective prioritization to ensure that software development aligns efficiently with user needs.

Keywords: Egalitarian Project; International Student Collaboration; Requirements Gathering; Requirement Prioritization; Waste Pickers.

1 Introduction

As part of the Egalitarian portfolio, an Erasmus+ program funded by European grants, Educado was designed to promote education and digital inclusion to waste pickers in Brasília. It aims to provide personalized content based on the knowledge needs of users with little access to education. Given the social relevance of the solution, ensuring that the digital platform effectively meets user needs requires a new software requirements list for the developers to work with.

Since 2018, the app (software designed for users) and website (designed for content creators) have been prototyped, developed, and improved. Throughout the Educado concept, different development cycles were implemented, each with distinct strategies and outputs. These phases contributed to the platform's evolution and generated documentation that now serves as the basis for the current study (Melo, 2024).

However, how can users' needs be identified, prioritized, and implemented consistently and efficiently? The present study aims to structure and prioritize the requirements for the continued enhancement of the Educado application and website.

Insights into user needs were documented in earlier phases of the project through exploratory initiatives and stakeholder interactions. These prior findings are consolidated to support the current refinement of requirements (Nunes et al., 2023).

Market research is also necessary to explore new potential features. It is characterized by a divergent focus on uncovering previously unrecognized possibilities and a convergent focus on reaching conclusions based on previously raised hypotheses (Ferreira, 2023). Lastly, these requirements must be ranked and prioritized according to their importance and impact on future development.

The following sections present the research stages, including the methodologies applied, proposed solutions, and recommendations for future work.

2 Theoretical Reference

This section aims to map the literature on the topic, which will be divided into two subtopics.

2.1 Usability Testing

As La Bara et al. (2021) mention, "A broader definition of usability may include the user's experience of the quality of the product or system."

Therefore, usability can also be understood as "The ease of using and learning about these applications and websites is related to the concept of usability, thus generating software with a higher level of quality" (De Camargo, 2021).

In this context, it is also necessary to understand the concept of usability testing, which, in the words of Barboza (2023), is "a method of verifying the functionalities of the interface of a digital platform. It is used on websites, applications, and other tools, leading real users to perform certain tasks."

It should also be noted that the usability test must explain the reason for each planned activity and highlight how adding a new function can help execute the proposed tasks (Oliveira, 2021).

2.2 Requirements Gathering

After carrying out usability tests by the collectors, it is necessary to define the methodology for gathering requirements to be developed by the developers of the AAU Software Five discipline, based on the identification of usability testing needs. Silva (2023) states, "Requirements gathering is the process of identifying, documenting, and verifying users' needs and expectations for a software system. It involves collecting relevant information to understand the context, desired functionalities, and constraints that must be considered during software development."

In this context, the most frequently used methodologies for requirements gathering are interviews, surveys and questionnaires, meetings and scenarios, focus groups, brainstorming, and JAD/RAD (Siqueira, 2023). Analyzing each method is essential for selecting the most coherent research field.

In the words of Siqueira (2023), "Interviews are the most used elicitation techniques, commonly used in any development as they represent one of the most natural forms of communication between people". Questionnaires "are used in various scientific areas, such as opinion polls, censuses, and other research types". However, it is crucial to design questionnaires carefully to ensure that questions are clear and relevant to the research objectives.

Brainstorming is one of the oldest and most well-known group meeting techniques for generating ideas. In the context of requirements gathering, brainstorming allows each person to inspire the other to create ideas that can contribute to solving the problem, whether in one or several meetings.

Regarding JAD (Joint Application Design), according to Siqueira (2023), "It was developed by IBM to accelerate the development of information systems and is based on group dynamics accompanied by planning, structuring, and systematization of meetings."

Finally, the methodology used to gather requirements was based on two stages of work: the analysis of usability tests and market research. The usability tests were carried out at the beginning of the year, and the latest tests served as input to gather the requirements for the app and website's functioning and improvement. Furthermore, other features could be identified during market research with different platforms.

2.3 Mudge Diagram

The Requirements Prioritization Matrix, also known as the Mudge Diagram, is a tool for systematically ranking requirements based on their relative importance. The model was initially used in Value Engineering and has since been widely adapted for prioritizing requirements in engineering projects and product development (Camolesi, 2020).

This approach relies on pairwise comparisons between requirements: each pair is evaluated by relevance, with weights assigned using an ordinal scale. After all comparisons, the values are summed to rank requirements by priority, from highest to lowest. This technique facilitates decision-making in projects with limited resources, ensuring that efforts are focused on the most impactful requirements (Souza et al., 2021).

In addition to being simple to apply, the Mudge Diagram is effective in collaborative contexts and can be adapted for different types of evaluations, including those involving multiple evaluators or weighted criteria. In product engineering projects, such as medical tools or educational software development, it has proven valuable in guiding the design phase based on structured data.

3 Methodology

This section presents the methodology used during the research. In it, the applied method and its structure will be explained.

3.1 Research Method

The methodology used was applied in nature, with an exploratory objective and a qualitative approach. The case study of the Educado project was used as a research strategy. Applied research "refers to research designed to develop new knowledge for practical purposes" (Pereira, 2020). This way, the study's nature is applied as it addresses a real problem facing collectors.

The research aims to deepen the understanding of the problem and expand knowledge on the topic, so it falls into the exploratory case study category. The approach is classified as qualitative, which attempts to understand better why things are the way they are in the social world and why people act the way they do. Ernest et al. (2023).

3.2 Research Structure

The research structure was composed of 5 stages, exemplified by Figure 1.

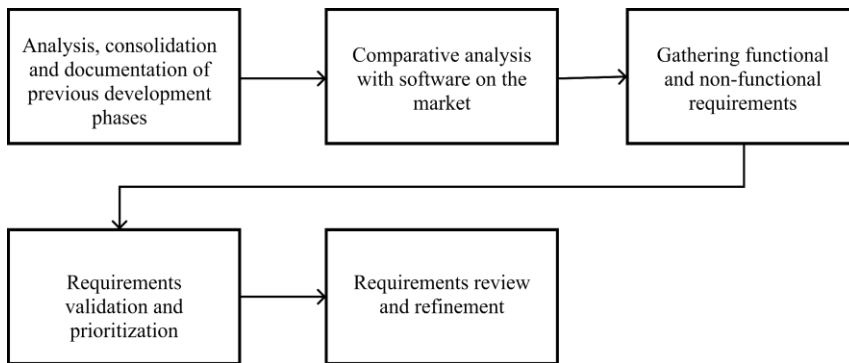


Figure 1. Study methodological steps.

The first stage of this research evaluates the progress of software development up to the current stage based on the proposal. Based on this assessment, the work will be consolidated and adequately documented, providing a structured basis for the subsequent stages of the research. Furthermore, a backlog was created to guide future activities.

Subsequent steps should involve proposing new solutions based on comparative analyses of other software available on the market. This helps understand the strengths and weaknesses of the Educado system compared to similar systems.

Based on these analyses, the outputs were formalized by defining functional and non-functional requirements. These requirements were identified and refined using results from previously conducted usability tests. Although new usability tests were not performed during this project, the insights from earlier evaluations were used to inform the requirement prioritization process. After determining the requirements, the list was reviewed and organized for formal delivery.

4 Results and Discussions

This section presents the requirements identified based on the results of usability tests carried out in earlier stages of the project, which were used as input for this study. It also includes the outcomes of the last development cycle, a comparative analysis, and the requirements prioritization process, culminating in the final list of requirements to be developed by students at Aalborg University in the upcoming semester.

4.1 Comparative Analysis

The first stage consisted of synthesizing the development of the 2023 Educado version, represented by Figure 2. It involved analysing screens already developed for the website and the mobile app and evaluating developer performance from the previous development cycle. These elements were transformed into a formal report to guide the following phases of the project.

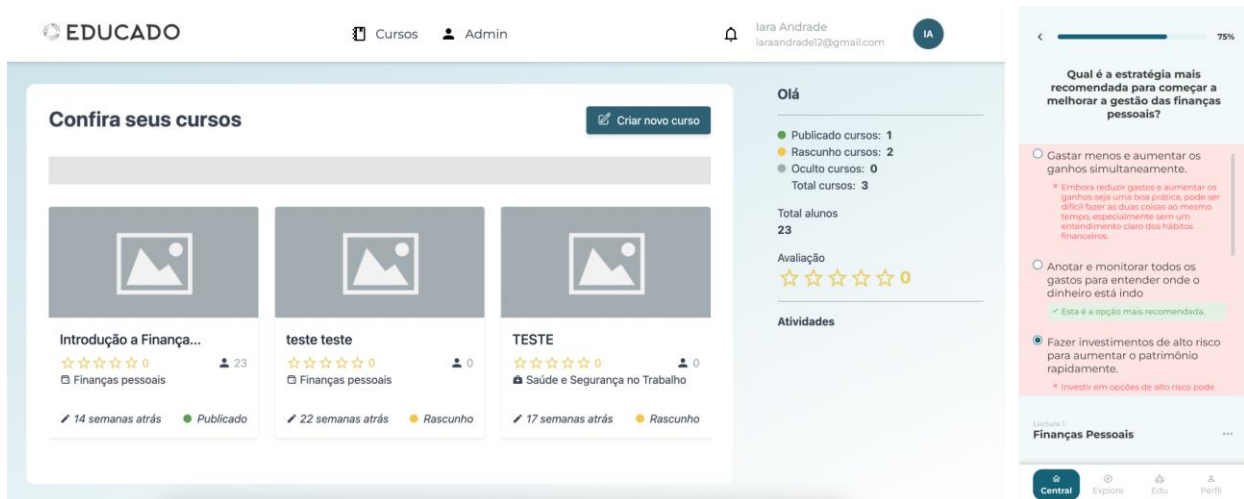


Figure 2. 2023 Version of the Educado Website and App.

Drawing from consolidated documentation, the comparative analysis provided an overview of the project, helping identify outdated requirements and opportunities for new functionalities, structured through a SWOT matrix and benchmarking. The matrix was conducted to assess the Educado platform's strategic position and define future enhancements, offering a perspective on internal capabilities and external challenges (Yadav & Sharma, 2020). The identified topics were:

- **Strengths:** Has a certificate from the University of Brasília, a renowned institution; international recognition through partnership with Aalborg University; offers free courses.
- **Weaknesses:** Decentralization of work; lack of "know-how" from students to use the app; communication difficulties with developers (different languages and countries).
- **Opportunities:** Focus on a specific niche (waste pickers); few competitors in the same niche; received investment from the Egalitarian project and UnB for development.
- **Threats:** Lack of attention to LGPD requirements; difficulty of use by illiterate users; possible breaches of the user data storage system.

Based on a benchmarking analysis, new features were identified to enhance the platform's experience. For the mobile app, improvements include a general ranking system, post-exercise feedback, access to downloadable materials, a centralized progress area, social media integration, completion certificates, and weekly performance reports. On the website, navigation guides, student-view simulation, multi-instructor courses, and weekly performance tracking were introduced. This comparative study highlighted usability best practices and supported mapping features aligned with market-leading solutions.

4.2 Gathering Requirements

The detailed survey introduces functional and non-functional requirements for the Educado app and website systems. It aims to identify the project status while providing an overview of the functionalities and their classifications in terms of progress. 144 (one hundred and forty-four) requirements were raised.

The requirements were classified into five distinct status categories to enhance the efficiency of management and monitoring of progress, which we can mention: new - newly identified requirements that have not yet been worked on; improvement - existing requirements that require usability improvement; error - requirements related to defects or bugs that need to be corrected; untested - requirements implemented, but have not yet undergone validation testing; done - requirements implemented and validated.

Figure 2 presents the status distribution of the 62 website requirements, revealing that the majority (45%) remain in the not tested category. The 27% of new requirements reflect the ongoing project. Improvements

and bugs each account for 10% and 8%, respectively, emphasizing the iterative refinement process. Meanwhile, only 8% of the requirements have reached the done status.

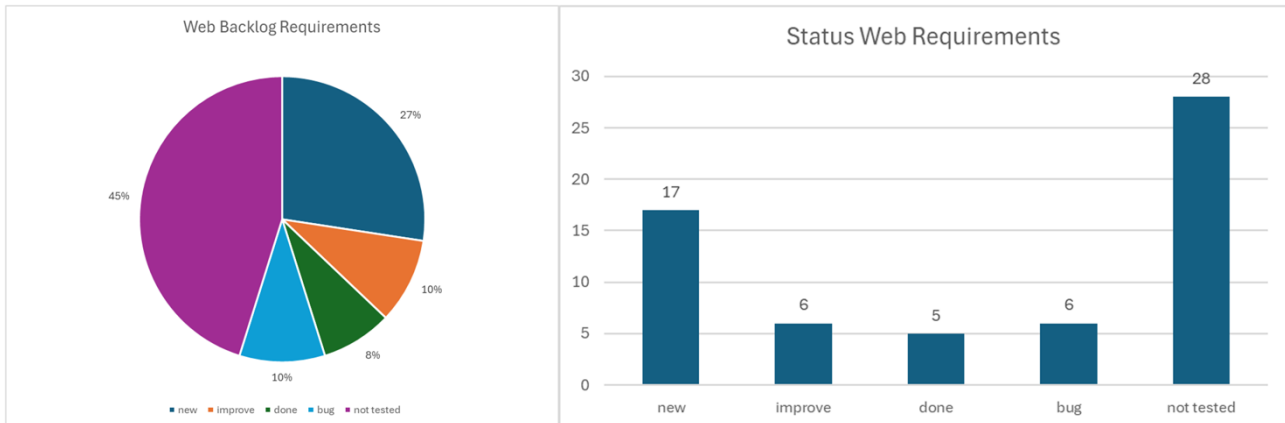


Figure 2. Distribution of Web Requirements by Status in the Educado Project.

In contrast, Figure 3 illustrates the distribution of the 82 app requirements. The new category holds 35% of the requirements, representing an evolution in functionalities for the end users. 24% are improvements, while 11% are bugs, indicating a need to refine the current app. Only 14% of the requirements are completed in the done category, and 16% are not tested.



Figure 3. Distribution of App Requirements by Status in the Educado Project.

This analysis provides a development overview of each platform and supports the development prioritization presented in the next section.

4.3 Requirements Prioritization

Requirements prioritization can be used to select which customer requirements will or will not be included in the product. The software establishes relative preferences or needs among requirements and defines a sequential order.

For this research, the requirements prioritization methodology used was the Pairwise Comparison Matrix, also known as the Mudge Diagram. This method allows the comparison, in pairs, of a set of customer requirements to determine the relative importance of each one (Nogueira, 2023). In that case, the requirements are catalogued as letters (A, B, C...n), and a table is created comparing each requirement and assigning its importance value from 0 (equal importance) to 5 (critical importance).

Therefore, the Educado requirements were prioritized through six Mudge Diagrams: three for the app system and three for the website. Each set of diagrams categorizes requirements into three groups: new requirements, improvement requirements, and error-related requirements, comparing items within the same category. In

order to illustrate this process, Table 1 presents the updated list of error-related requirements for the app, each with a clear identifier for use in the corresponding diagram.

Table 1. Error-related requirements list catalogued for the Educado app.

ID	Requirements
A	As a waste picker, I would like to click on the button to register and go to registration page
B	As a waste-picker, I want to have the ability to register as a new user, so that I can log in to the application going forward
C	As a waste picker, I want to learn more about the course before subscribing, so that I can choose better
D	As a waste picker, I want to be able to review the exercises and get feedback from it
E	As a waste picker, I want to be able to finish de exercise
F	As a waste picker, I want to see me getting points after completing exercises on a course
G	As a waste picker, I want to see all the courses that I did download when I am offline
H	As a waste picker, I want to upload a new profile picture or choose the default profile picture in my profile settings
I	As a waste picker, I want to be able to see and edit relevant data about my profile on the profile page.

Subsequently, the Mudge Diagram was built as presented in Table 2, which prioritizes the app error-related requirements. This structured visualization offers a systematic comparison that resulted in absolute and relative scores, indicating the frequency and impact of each requirement within the dataset. Higher scores indicate more critical requirements or are frequently associated with multiple errors, necessitating prioritization in the debugging and refinement process.

Table 2. Mudge Diagram of error-related requirements for the Educado app.

	1	2	3	4	5	6	7	8	9		
ID	A	B	C	D	E	F	G	H	I	Absolute Score	Relative Score
A	A	A1	A3	D2	0	0	A3	A1	A1	9	13,85%
B		B	B3	0	E3	0	B1	0	I1	6	9,23%
C			C	D3	E5	F3	G2	H1	I3	0	0,00%
D				D	E3	D1	D3	D1	I1	10	15,38%
E					E	E3	E3	0	E1	24	36,92%
F						F	F1	F1	I1	5	7,69%
G							G	0	I1	2	3,08%
H								H	I1	1	1,54%
I									I	8	12,31%

The other constructed Mudge Diagrams follow the same structure pattern that will guide the development team with a data-driven approach. This method ensures the software resolution is aligned with project goals and the user's needs while first addressing the most impactful issues to optimize system functionality. Following this, an organized list of requirements was created for developers from the Software Five discipline at AAU to work in the second semester of 2024. The following section will detail these requirements.

4.4 List of Requirements to be Developed

Drawing upon the Mudge Diagram method, the requirements were organized in descending order of priority, with their ranking classification, corresponding letter for identification, and description. These are described as

user stories, an agile methodology technique to make the system's functionalities straightforward from the end user's point of view, facilitating the team's understanding (Domínguez et al., 2024). Table 3 presents the result of the app error-related requirements with that layout.

Table 3. Prioritized list of error-related requirements for the Educado app.

Priority	ID	Requirements
1	E	As a waste picker, I want to be able to finish the exercise
2	D	As a waste picker, I want to be able to review exercises and receive <i>feedback</i> from them
3	A	As a waste picker, I would like to click the button to register and go to the registration page
4	I	As a waste picker, I want to see and edit relevant data about my profile on the profile page
5	B	As a waste picker, I want to be able to register as a new user so that I can <i>log</i> in to the app going forward
6	F	As a waste picker, I want to see my points being scored after completing exercises in a course
7	G	As a waste picker, I want to see all the courses I have downloaded when I am offline
8	H	As a waste picker, I want to upload a new profile photo or choose the default photo in my settings
9	C	As a waste picker, I want to know more about the course before signing up so I can choose better

Replicating the established pattern illustrated in Table 3, additional prioritized lists were created for the remaining requirement categories. The six sets (new and improvement-related requirements for the app and error-related, new, and improvement requirements for the website) reflect the categorization and quantity of requirements identified in Section 4.1. This means that the method was consistently applied to all 144 requirements.

Therefore, the final list contains the expected outcome of further software implementation, ensuring incremental value delivery aligned with user needs.

Based on the competitive analyses and document consolidation, the outputs could be formalized by defining functional and non-functional requirements. These requirements were validated and prioritized according to the research's needs and objectives. After determining the requirements, the list was reviewed and refined to prepare it for formal delivery.

5 Conclusion

Consolidating the gathering and prioritization of app and website requirements for Educado, an extension project with international cooperation, is relevant to the discipline of Software Five from Aalborg University (AAU), which is responsible for software development. Students aim to deliver incremental value to users through agile methodology, Scrum, using the problem-based learning methodology (PBL), which will scope the requirements defined in this work.

The project aimed to identify, prioritize, and implement improvements to the Educado app and website to improve the user experience. In this way, it was possible to carry out a comparative analysis of the screens already developed throughout the project and a market analysis to identify outdated requirements and opportunities for new functionalities. It was also possible to classify the requirements into five status categories to subsequently prioritize them. Finally, as the last result of the research, the team summarized the list of requirements to be developed next. Thus, the objective of the work was completed.

Due to communication issues with the previous semester's developers, the workshop to understand their perception of the format, beyond the collected data, could not be held. Additionally, status requirement updates were delayed as the other team was still testing the application and website. These challenges highlight opportunities for future work on improving user-developer communication through requirements.

However, the research results were successfully achieved, with requirements raised, categorized, and prioritized into transparent and objective lists. This work provides a solid foundation for the Educado project and its software development cycle in the second half of 2024 in partnership with Aalborg University (AAU) developers. Therefore, it is ensured that future implementations are aligned with users' needs and expectations, with a solid basis for usability tests at the University of Brasília, followed by the development.

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EcoLink: A Digital Platform for Sustainability, Community Engagement, and Waste Management

Pedro Gonçalves Prazeres¹, Yasmim Bezerra Oliveira Altoé¹, Davi Cunha Vanderlei¹, Simone Borges Simão Monteiro¹, Iara Gomes Andrade¹

¹ Production Engineering, Faculty of Technology, University of Brasilia, Brasilia, Brazil

Email: pedroprazeres98@yahoo.com.br, bezerrayasmim7@gmail.com, 211038333@aluno.unb.br, simone_simao@yahoo.com.br, 170012484@aluno.unb.br

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Abstract

The growing awareness of sustainability has driven the development of technological solutions aimed at centralizing and enhancing sustainable initiatives. The EcoLink app emerges as a digital platform designed to integrate information, foster community engagement, and encourage eco-friendly practices, promoting accessibility and positive environmental impact. The project was proposed by students participating in the Egalitarian project, under the ERASMUS+ program funded by the European Union. This international program seeks sustainable solutions for global challenges by connecting students and professors from different countries and applying an active learning methodology in project development. The research follows a qualitative, exploratory, and applied approach, focusing on three key aspects. Initially, a study on sustainability, conscious disposal, and recycling was conducted within the Brasília community, engaging over 230 participants. This study enabled the identification of users' specific needs, allowing for the development of personas, brand identity, and the structuring of high-level functional requirements for the app. This article aims to present the EcoLink modules, which include: i) Marketplace, connecting consumers with certified businesses that offer sustainable products; ii) Information hub, functioning as a repository of specialized sustainability content, enabling waste pickers to educate the public on proper waste disposal; iii) Reuse and recycling, facilitating the donation and collection of recyclable materials, ensuring their proper allocation to sustainable initiatives; and iv) Community, promoting social interaction through experience-sharing and access to eco-friendly events. The next steps involve app development, consolidating the planned features and ensuring their implementation for the target audience. The EcoLink app aims to democratize access to sustainability, strengthen the green economy, and foster collective engagement, establishing itself as a key solution for environmental awareness and social transformation.

Keywords: Egalitarian Project, Digital Platform, Community Engagement, Conscious Disposal, Active Learning.

1 Introduction

Contemporary society is characterized by an exacerbated consumption model, in which the creation of false needs drives the uncontrolled acquisition of goods, resulting in a growing production of municipal solid waste (Almeida et al., 2020). This scenario has become one of the central issues on global sustainability agendas, being a complex and multifaceted problem. Factors such as rapid population growth, the widespread generation of non-recyclable materials, and inadequate management practices exacerbate the situation, leading to negative environmental impacts, such as biodiversity loss and the intensification of climate change (Guimarães, 2019).

The advancement of digital technologies has profoundly changed the way information is disseminated and absorbed, expanding access to knowledge and facilitating environmental awareness. Environmental education plays a critical role in this process, as without clear guidelines and accessible knowledge, concern for the environment often fails to translate into concrete actions (Da Silva Lima et al., 2020).

The lack of centralized and accurate information about sustainable initiatives hinders both individuals interested in contributing and initiatives that depend on support and visibility, highlighting the need for platforms that connect society to viable and accessible solutions (Aquino; Castilho Jr; Pires, 2009). In this

context, higher education institutions and research centers have played a significant role in developing solutions focused on environmental management, promoting projects that integrate education, technology, and sustainability (Brasi et al., 2019).

The Egalitarian project, an Erasmus+ initiative of the European Union led by students, aims to develop innovative solutions for waste management and the improvement of waste pickers' quality of life in Brasília, aligning with the Sustainable Development Goals (SDGs) of the 2030 Agenda. The project encourages collaborative work among students from different countries and disciplines—mostly from engineering and computer science—with support from professors and academic institutions. One of the main goals of Egalitarian is to create digital solutions to optimize waste management and enhance the social impact of these initiatives (Egalitarian, 2025).

Thus, the EcoLink app emerges with the goal of integrating information, promoting environmental education, and stimulating the circular economy through interaction among users, waste pickers, and companies. This article aims to analyze the potential impact of EcoLink and present the stages that guided its development. Furthermore, the functionalities of each module of the platform will be detailed, highlighting how its tools contribute to social engagement, environmental awareness, and the adoption of sustainable practices. EcoLink, therefore, positions itself as an accessible and innovative resource capable of driving meaningful transformations and promoting a more responsible and conscious consumption model.

2 Theoretical Framework

The Egalitarian project is an initiative that seeks to encourage participants to work in multicultural teams, addressing real-world challenges related to the United Nations' Sustainable Development Goals (SDGs) of the 2030 Agenda. The project's proposal aims to stimulate the development and implementation of innovative solutions focused on optimizing solid waste management and improving the working conditions and quality of life of waste pickers in Brasília (Egalitarian, 2025).

As part of the European Union's Erasmus+ program, Egalitarian is based on the use of active learning methodologies, particularly Project-Based Learning (PjBL), an educational approach in which students occupy a central role in the learning process and are encouraged to solve authentic problems in collaborative contexts. The PjBL methodology is characterized by promoting practical problem-solving while simultaneously fostering the development of essential scientific skills. According to Nurhidayah et al. (2021), students engaged in PjBL acquire competencies to address scientific questions through hypothesis formulation, planning and conducting experiments, as well as making careful observations and performing rigorous data analysis.

To meet the labor market demand for professionals with solid knowledge in project management, the University of Brasília has structured the Production Engineering program around seven courses called Production Systems Projects (PSPs), taught sequentially from the fourth to the tenth semester. These courses, grounded in the PjBL methodology, aim to develop both specific technical competencies and essential transversal skills in students, such as leadership, proactive management, effective communication, and teamwork capabilities (Monteiro et al., 2017).

Another key aspect of the Egalitarian project's approach lies in the development of innovative digital solutions. In this context, students are encouraged to explore contemporary technological tools applied to sustainability and efficient waste management. Working in interdisciplinary groups, participants develop digital solutions that seek to optimize key processes such as selective waste collection and the productive inclusion of waste pickers. The replicability of these solutions is a critical factor, allowing successful initiatives in Brasília to be adapted and implemented in other global contexts. Additionally, the emphasis on digital development enables

participating students to acquire skills valued in the contemporary job market, such as process automation, data analysis, and the use of collaborative digital platforms.

3 Methodology

3.1 Research classification

This is an applied research project, as it aims to generate knowledge directed toward solving a practical problem. According to Dresch et al. (2015), applied research seeks to create a direct impact on reality, unlike purely theoretical research, which aims to expand knowledge without immediate application. The method adopted in this research is inductive, as it begins with the observation of specific situations to build broader knowledge. The starting point was the analysis of the challenges faced by recyclable material collectors and the community in Brasília regarding waste management. Based on this information, a technological solution applicable to the studied context was structured.

According to Prodanov and De Freitas (2013), exploratory research is appropriate when the goal is to gain greater familiarity with a problem and to structure hypotheses or conceptual models. In the case of EcoLink, the study was conducted to map user needs and understand how a digital platform can contribute to promoting sustainable solutions and environmental education, thus adopting an exploratory character. Regarding the research approach, this is a qualitative study, as it aims to understand users' perceptions, behaviors, and expectations related to practices and the use of sustainable platforms. As described by Creswell et al. (2017), instead of using quantitative, statistics-based approaches, this research prioritizes the analysis of form, interviews, and observations to support the development of the application. The development of EcoLink is considered a case study, as it was analyzed within the specific context of the city of Brasília and its solid waste management network, allowing for a detailed examination of local challenges and opportunities.

3.2 Research structure

The research was structured in sequential stages, ensuring a systematic process for the development of the EcoLink platform. The main phases that guided the study are described below, as shown in Figure 1.

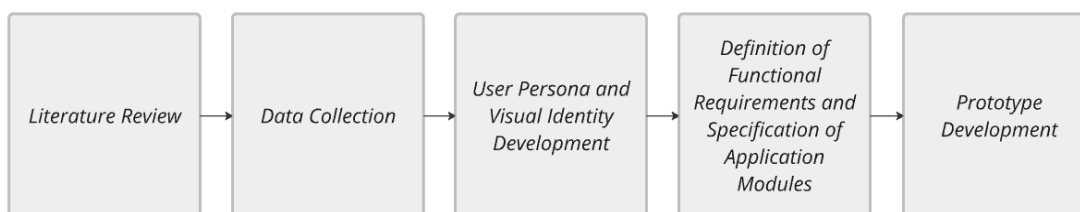


Figure 1: Stages of the research, Developed by the authors (2025)

In the first stage, a comprehensive literature review was conducted on topics related to sustainability, circular economy, waste management, and digital platforms. This stage was fundamental in building the theoretical foundation of the study. Data collection took place in the second stage, during which a form was administered to over 230 participants, including community members, recyclable material collectors, and environmental specialists. The goal of this phase was to understand the main challenges related to sustainable practices and expectations regarding a digital solution. Based on the analysis of the collected data, representative personas of the application's user profiles were created, helping to define the user experience and develop EcoLink's

visual identity. Drawing on the identified needs, the functional requirements of the app were established to ensure that its features addressed the demands mapped during the research, as well as to define the user journey flow. The main modules of EcoLink were then defined: i) Marketplace, to connect consumers with sustainable businesses; ii) Information Hub, to provide educational content; iii) Reuse and Recycling, to facilitate donations and collection of recyclable materials; and iv) Community, to promote sustainable interactions and events. Finally, in the last stage, wireframes and interactive prototypes were created to visualize and test EcoLink's usability, allowing for adjustments before the start of technical development.

4 Results and Discussion

To clearly understand the context in which the application is inserted, a survey was conducted through a form consisting of 24 questions, structured into three main sections: Demographic Analysis, Interest in Sustainability, Conscious Disposal and Reuse, and Applications Related to Sustainability. The survey was applied in the Federal District and received 230 responses. The results provided an understanding of the population's interest in sustainability issues, with approximately 80% of respondents stating they were interested in the topic. However, 204 participants indicated that they were unaware of any application or platform that centralizes sustainable information in the region, highlighting the relevance of creating EcoLink. Additionally, the responses collected allowed for the identification of the themes most valued by potential users, such as locating nearby recycling points, practical sustainability tips, places to buy sustainable products, and information on reuse and recycling. These insights were crucial in structuring the application's modules, guiding the development of features aligned with the preferences and needs of the population. Based on the data collected and analyzed, it was also possible to define the personas that guide the project.

This preliminary foundation drove significant advancements in the development of EcoLink in the second half of 2024. Among the key results, a clear definition of the application's modular structure stands out, organized into four main areas: Marketplace, Information Hub, Community, and Reuse and Recycling. Additionally, the functional requirements of each module were defined and detailed by the PSP5 team, ensuring that the features were aligned with EcoLink's goals, as shown in Figure 2.

Marketplace

Descrição:

Um espaço exclusivo para empresas certificadas venderem produtos sustentáveis de diversas categorias, conectando consumidores conscientes a opções que promovem impacto positivo no meio ambiente.

Usuários

Tela 1: Home Marketplace

Prioridade: Must Have

Ideia Geral:

Apresenta produtos sustentáveis em destaque, categorias principais e lojas certificadas. É a porta de entrada para o usuário explorar produtos e marcas.

Requisitos	User Journey	Elementos visuais	Interações	Observação	Priorização
Produtos e Lojas	O usuário acessa a tela inicial e visualiza produtos em destaque, lojas recomendadas, principais categorias e sugestões personalizadas com base no comportamento de navegação.	Carrusel de produtos, lojas com nome e logo.	O usuário pode clicar em produtos ou lojas para acessar mais informações.	Referências: Méliuz, Nubank (sessão shopping), Banco Inter (sessão Shopping), Ifood, Enjoei	Must Have
Busca de produtos, lojas ou categorias	O usuário utiliza a barra de busca para localizar produtos ou lojas específicos, digitando palavras-chave e recebendo resultados instantâneos	Barra de busca fixa no topo com placeholder "Buscar por produtos ou lojas".	O usuário digita um termo e recebe sugestões ou resultados ao pressionar "Enter".	Quando o usuário clicar, é redirecionado para a Página de Pesquisa	Should Have
Notificações e Promoções	O usuário visualiza banners de promoções e notificações importantes na página inicial, clicando neles para obter mais informações.	Banner fixo ou rotativo com informações sobre promoções ou novidades do marketplace.	O usuário pode clicar no banner para explorar mais detalhes sobre as promoções exibidas.	Referências: Méliuz, Nubank (sessão shopping), Banco Inter (sessão Shopping), Ifood, Enjoei	Should Have

Tela 2: Página da Loja

Prioridade: Must Have

Ideia Geral:

Mostra os detalhes gerais da loja, como logo, descrições e os produtos disponíveis. Permite

Figure 2. Example of the detailed functional requirements of the EcoLink modules, Developed by the authors (2025)

To enable visualization of the platform's structure and simulate the user experience, the PSP2 team of the 2024.2 semester developed the first interface prototypes for each of the modules highlighted earlier.

4.1 Modules

4.1.1 Marketplace

The Marketplace module was designed as an exclusive space for certified companies to sell sustainable products from various categories. This environment aims to connect conscious consumers with purchasing options that promote a positive environmental impact and encourage responsible consumption practices. The goal is to ensure that all products available on the application meet pre-established sustainability criteria, strengthening user trust and encouraging the choice of environmentally friendly alternatives.

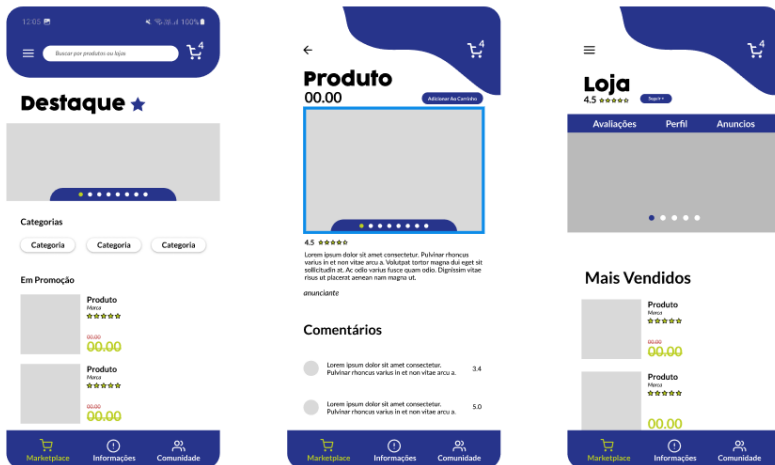


Figure 3: Marketplace screens prototyped by PSP2, Developed by the authors (2024)

As shown in Figure 3, the Marketplace module displays featured sustainable products, main categories, and certified stores, functioning as the entry point for the user to explore the marketplace. The requirements include product and store visualization, smart product search, and promotional notifications, promoting navigation and engagement with relevant offers. The purchasing journey is facilitated with a shopping cart, delivery and payment forms, order summary, and a simple and intuitive checkout process.

4.1.2 Community

The Community module was conceived as an interactive space that connects users and organizations engaged in sustainability issues, such as recyclable material collectors. Through videos, comments, and interactions, participants will be able to share experiences, discuss ideas, and promote initiatives that contribute to strengthening the community. This environment aims to create a support and collaboration network, encouraging user engagement and expanding the reach of actions in favor of the environment. It is important to highlight the relevance of the module, as the process of sustainable mobilization can be carried out through digital means.

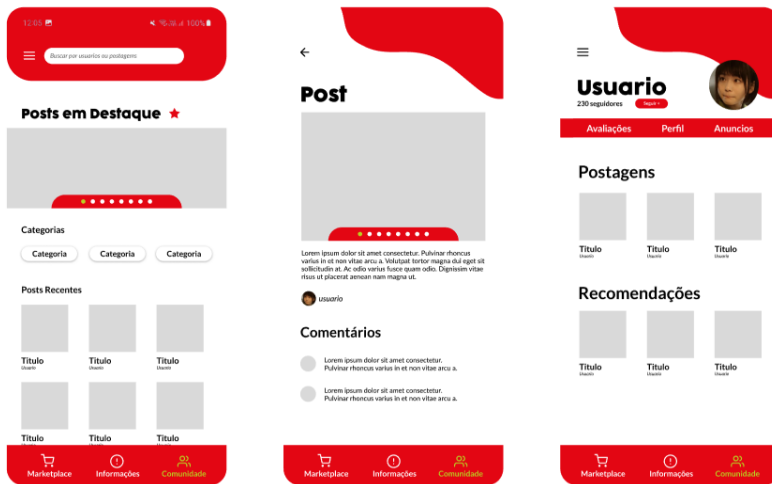


Figure 4: Community screens prototyped by PSP2, Developed by the authors (2024)

As shown in Figure 4, the Community module integrates functional requirements that promote the exchange of experiences among users, such as the display of posts, interaction buttons (like, comment, share), creation of publications, and advanced search for content and profiles engaged in sustainability.

4.1.3 Information Hub

The Information Hub module has as its main objective to centralize the dissemination of content on sustainability, offering users easy access to reliable and up-to-date information. In this space, specialized magazines, institutions, and experts will be able to share news, articles, and technical reports related to the environment, sustainable practices, and related topics. By gathering this material in a single environment, the application aims to promote awareness and broaden users' knowledge about the challenges and solutions for environmental preservation.

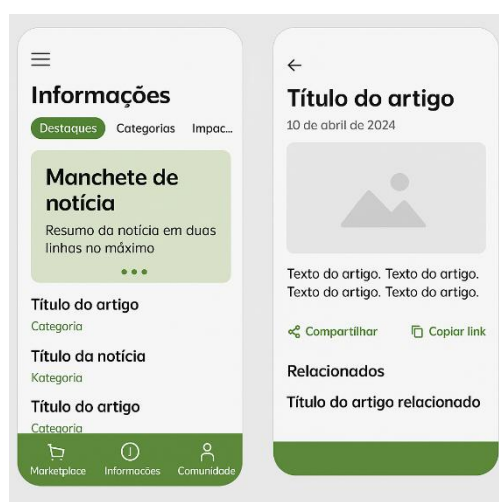


Figure 5: Information Hub screens prototyped by PSP2, Developed by the authors (2024)

As shown in Figure 5, the Information Hub module gathers content on sustainability in a space where authors can create, edit, and manage publications with images, categories, and engagement statistics. Users can access full articles, share content, and explore related materials. Navigation is optimized with features such as drafts, text formatting, and thematic filters.

4.1.4 Reuse and Recycling

The Reuse and Recycling module aims to facilitate the process of donating and collecting recyclable material to ensure that resources are allocated to sustainable initiatives, such as recycling cooperatives. In this environment, a map of the Federal District will be displayed, and collection points will be highlighted to show all the locations for receiving material in the region. This module seeks to ensure that the donation and disposal process is carried out consciously so that organizations receive the appropriate materials, properly organized.

Due to prioritization during development, the requirements for the module have not yet been raised. However, its development is planned for the next stages of the project, given its importance to the platform's proposal and the impact it will have on sustainable initiatives. Therefore, by breaking down each module of EcoLink, it was possible to validate the initial proposal, identify improvements for each module, and ensure that design decisions are aligned with the project's goals and the target audience's needs. The results obtained so far represent an important milestone in the development of EcoLink, establishing a solid foundation for the next phases of implementation and testing with users. The project remains aligned with the purpose of creating a digital tool capable of strengthening sustainable practices, promoting access to qualified information, and stimulating the creation of a community engaged in environmental preservation.

5 Conclusion

The integration of digitalization and sustainability carried out by the Egalitarian project not only fosters positive environmental impacts but also empowers students in the use of digital technologies aimed at improving the quality of life in vulnerable communities. This initiative reinforces the commitment of young people to socio-environmental transformation.

The adoption of Project-Based Learning (PjBL) in university courses was crucial both for the conception and structuring of the EcoLink application. This methodology enabled a practical and interdisciplinary approach, encouraging students to actively participate from the ideation phase to detailed planning and the definition of technical requirements for the application. Through this process, it was possible to systematize research and organize the essential artifacts for the implementation of the solution, ensuring a consistent theoretical foundation aligned with the real needs of the target audience. In this way, PjBL confirmed its effectiveness as a pedagogical strategy capable of bridging theory and practice, strengthening students' preparation to face real challenges and develop innovative solutions focused on environmental and social issues.

The results obtained indicate that EcoLink holds significant potential to centralize relevant information on sustainable practices, stimulate community engagement, and facilitate interaction between consumers, recyclers, and companies committed to sustainability.

As a recommendation for future work, it is suggested to begin the practical development of the application by creating a Minimum Viable Product (MVP). This approach will allow for the validation of the initial assumptions of the proposal and promote iterative improvements based on real user feedback. Additionally, the importance of establishing strategic partnerships with companies and institutions in the sustainable sector is emphasized to expand the reach of EcoLink and ensure its effective implementation. In this way, the project positions itself

as a promising digital tool to stimulate conscious consumption models and facilitate access to innovative sustainable solutions.

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Strategies for rapid learning in SuperPro Designer through a course on biotechnological process planning

Sebastian Cisneros-Hernández¹, Carolina Ramírez-Martínez¹, Juan Silvestre Aranda-Barradas¹, Alberto Ordaz^{1*}

¹Tecnologico de Monterrey, Escuela de Ingeniería y Ciencias, México.

*Email corresponding author: alberto.ordaz@tec.mx

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Abstract

Incorporating digital tools into engineering education is crucial for preparing students to solve real-world challenges. This study explores the use of SuperPro Designer as an active learning tool in a biotechnological process planning course, integrating Problem-Based Learning (PBL) and Project-Based Learning (PjBL) methodologies. The course aimed to accelerate software proficiency while improving interdisciplinary understanding of bioreactor scale-up, economic assessment, sustainability, and industrial regulations. Students were first introduced to SuperPro Designer through guided practical exercises available via live sessions and recordings. They then engaged in a PBL-based challenge, where they scaled up a bioreactor and assessed its economic and environmental impact. Finally, students conducted an open-ended bioprocess design project, selecting a product, defining a market strategy, and performing a techno-economic feasibility analysis. This structure encouraged critical thinking and real-world problem-solving. Student performance was assessed through a pre-test and post-test comparison using Wilcoxon Signed-Rank Test, revealing a significant shift toward high proficiency levels. A post-course survey further highlighted that student, regardless of proficiency level, reported high confidence in key bioprocess design skills, reinforcing the effectiveness of this approach. These findings suggest that integrating digital tools with active learning strategies can effectively bridge theoretical knowledge and practical application in engineering education. This approach is transferable to other engineering disciplines that require techno-economic analysis, strategic planning and scale-up decision-making.

Keywords: SuperPro, Bioprocess, Scale-up, Project-Based Learning, Engineering Education, Simulation-Based Learning, Bioprocess Simulation, Techno-Economic Analysis

1 Introduction

Nowadays, bioprocess engineering courses integrate various innovative teaching strategies to enhance student comprehension, and the application of concepts related to the modern biotechnological industry. These courses emphasize teaching industrial-scale fermentation design and control, solving open-ended design problems, and acquiring practical fermentation skills. Undergraduate students gain a comprehensive understanding of biochemical processes, industrial biotechnology fundamentals, kinetics, and reactor calculations (Alam & Zakaria, 2021; Anakin & McDowell, 2021; Pazos et al., 2011). Courses typically cover unit operations such as sterilization, aeration, and stirring in bioreactors, progressing to the scale-up of biochemical processes. To achieve these objectives, diverse teaching strategies are employed, including lectures, tutorials, practical work, discussions, collaborative learning, small group discussions, journal reflections, case-based learning, lab work, service-learning projects, and industrial visits (Pazos et al., 2010). The continuous development of new learning materials aims to advance bioprocess engineering education, leading to high student satisfaction and active participation. Furthermore, the use of computational tools to support cooperative learning methods has shown significant improvement in student cognitive skills (Ballesteros Martin & Moral Rama, 2014; Martín-Lara & Ronda, 2020). Meticulously designed engineering courses that integrate theoretical and practical aspects, along with competencies like communication and teamwork, ensure comprehensive student learning. In this context of continuous improvement, the use of process simulators can significantly enhance student learning and engagement. Particularly, the use of SuperPro Designer, which contains a unique environment of process units fitting common bioprocess equipment, provides a

technological platform for students to model not only bioreactor operations under various conditions but several process units related to recovery and purification of bioproducts (downstream processing). This promotes a hands-on approach to learning that extends beyond theoretical concepts (Alam & Zakaria, 2021) or scholar lab experiments. The use of SuperPro Designer in education can significantly enhance students' competencies in biotechnological process planning and evaluation. The robustness of the software has been proven by several scientific articles devoted to systematically assessing the technical and economic viability of various processes, such as natural pigments production (Mora-Jiménez et al., 2024), alginate and fucoidan production from sargassum (Ramírez-Partida et al., 2024), recombinant protein production (Alkanaimsh et al., 2024), lipids production from microalgae (Valdovinos-García et al., 2024), bioethanol production from starch milk (Katanski et al., 2024), to name a few of the most recently published studies. Integrating the use of SuperPro into common bioprocess engineering courses at early stages of the academic life of Biochemical or Biotechnology engineering students is of great importance. The software supports the creation and analysis of complex mathematical models, essential for predicting and optimizing bioreactor performance, and provides students with advanced digital skills. To articulate biotechnological development, SuperPro Designer enables students to generate detailed quantitative and qualitative data for scientific arguments. It facilitates process documentation and report generation, supporting well-founded arguments in scientific texts and presentations. The software also allows students to simulate scenarios and assess the economic, social, and environmental impacts of their designs. This capability aids in constructing robust, scientifically validated arguments and fosters critical communication skills, essential for engaging diverse audiences in scientific and professional forums.

In this context, the main objective of this article is to design and apply strategies for accelerating mastery in SuperPro Designer by utilizing a course focused on biotechnological process planning. SuperPro Designer, therefore, plays a pivotal role in demonstrating key competencies in the articulation of biotechnological development as well as in biotechnological process planning and evaluation.

2 Methods and experimental settings

The course selected for this study was titled 'Planning of Biotechnological Processes'. It is an intensive 5-week course (16 hours a week) imparted to students in the 6th semester of Biotechnological Engineering at Tecnológico de Monterrey. The core of this course is the design, modeling, optimization, and technical and economic evaluation of a given bioprocess to produce a biomolecule of industrial interest. The total number of students impacted in this study was 40, divided into 2 groups due to the availability of the computing classroom where the SuperPro Designer v12.0 was installed. The students had no previous experience in the use of SuperPro Designer or biotechnological process planning. However, they did have experience using modeling software like Mathematica and Matlab. Additionally, the students took two previous courses focused on the usage of bioreactors for carrying out different experimental cultures and a course on bioseparation strategies tailored to biomolecule physicochemical characteristics.

2.1 Teaching strategies

Methods and teaching techniques employed in the course include a combination of theoretical analysis, practical applications, case studies, practical exercises (one activity), and assessments (two exams). Presentations of situational problems and evidence-based evaluations are also included. Support tools comprise tutorials, instructional videos, discussion forums, and extensive tutoring sessions. Our teaching strategy is principally rooted in Project-Based Learning (PjBL), a learner-centered approach that promotes deep learning through the development of real-world projects, emphasizing teamwork, knowledge integration, and artifact creation (Guo et al., 2020). In engineering education, PjBL not only facilitates content mastery but also

fosters transversal competences such as design thinking, collaboration, and effective communication (Bes-Piá et al., 2023). These aspects were embedded in the course through simulation-based design challenges using SuperPro Designer, supported by guided resources and iterative feedback. We further encourage collaborative learning to address complex problems, fostering teamwork and communication skills. Continuous assessment methods monitor student progress and guide learning effectively. Digital resources enrich the experience, with tutorials, instructional videos (which can be consulted per request to the corresponding author), and online forums, allowing students to learn at their own pace and revisit complex topics as needed. Based on performance, students' proficiency in SuperPro Designer was classified as follows: proficient (91–100 points), solid (81–90), basic (71–80), and incipient (below 70).

2.2 SuperPro designer educational strategies

SuperPro Designer is a comprehensive software tool that primarily performs two essential processes: material and energy balances for each piece of equipment specified in the process diagram, and economic analysis of all aspects defined within the process diagram. To operate effectively, the software requires various types of information of a biotechnological process. Experimental data is crucial, including cell culture data, operational data of bioreactors, and separation and purification data. Theoretical information is also necessary, such as the physical and chemical properties of components, material and energy balances, equipment design parameters, and mathematical models and design equations. Additionally, SuperPro Designer incorporates supplementary information like raw material costs, auxiliary services, equipment expenses, regulations and standards, and market data. By integrating this comprehensive data set, SuperPro Designer facilitates detailed and accurate modelling, analysis, and optimization of bioprocesses, allowing for informed decision-making and efficient design and operational planning. It was proposed to follow a smart sequence of steps for the fast learning of this important tool, which comprises the following steps: (i) Start by defining the process diagram to establish a clear visual representation of the workflow. (ii) Next, enter all relevant data, including experimental, theoretical, and supplementary information. (iii) Proceed with the simulation and optimization phase, where the process is modelled, and its efficiency is enhanced. (iv) Conduct an economic and feasibility analysis to evaluate the financial and practical viability of the process. Finally, (v) iterate and validate the model by refining inputs and verifying results to ensure accuracy and reliability. Figure 1 illustrates the smart sequence and highlights the key stages involved in each step.

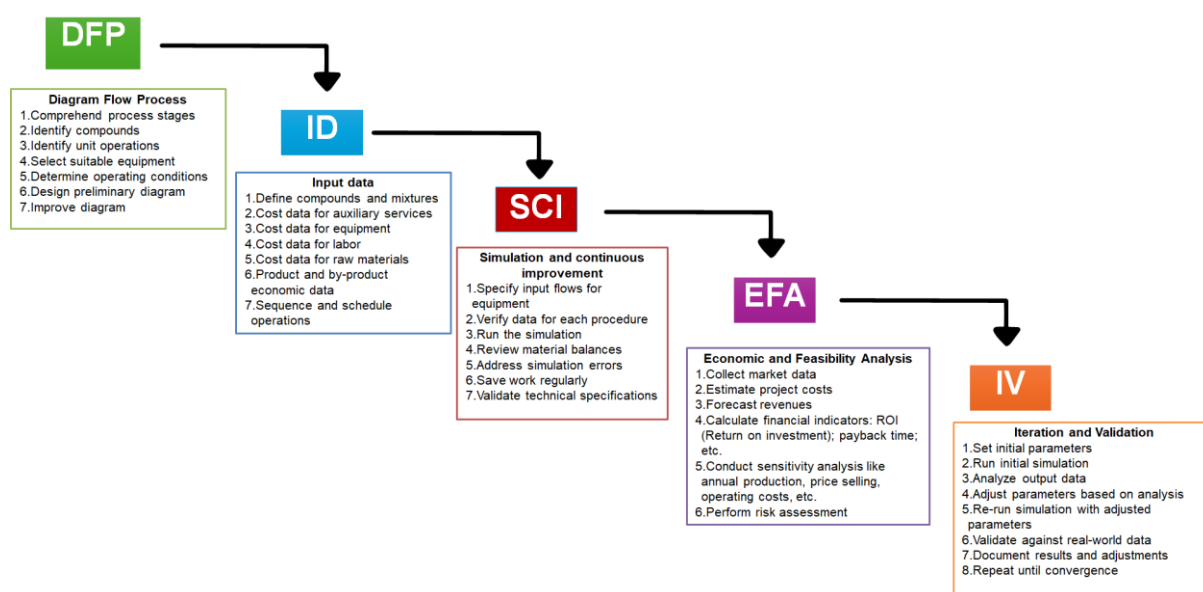


Figure 1. Smart steps sequence for rapid learning in SuperPro designer.

2.3 Description of the course assessment

In the evaluation of progress for SuperPro Designer strategies aimed at rapid learning, various criteria and evaluation instruments are employed. These include an analysis of projects carried out by students, and a post-course survey. The data collection and analysis procedures utilize both qualitative and quantitative methods, supported using statistical analysis software to ensure accurate and comprehensive assessment.

To evaluate the effectiveness of the active learning strategy implemented with SuperPro Designer, a comparative analysis of student performance was conducted using (i) two quizzes, (ii) one main activity and (iii) a final project. The first quiz was administered during the initial week of the course, when students had received introductory training in the use of the software, while the second was delivered in the second week, after comprehensive instruction and more hours in practical engagement. In both cases, students were tasked with addressing a bioprocess design challenge under defined production and operational constraints using SuperPro Designer. The activity consisted of designing and simulation of the process for protein recovery that was done during a previous experimental course. Finally, the last evaluation was designing and simulating a case of study based on carotenoids, lipids and lipases production. The distribution of grades of the assignments was first assessed using the Anderson-Darling test, which confirmed a deviation from normality (p -value < 0.005 in both cases). Accordingly, the Wilcoxon Signed-Rank Test was employed to evaluate the differences between paired samples (Coakley & Conover, 2000). A statistically significant improvement in performance was observed (p -value < 0.005), suggesting that proficiency in bioprocess design was enhanced through structured use of the software over the course period.

The post-course survey was designed to evaluate students' perceptions of the most critical factors for strategic bioprocess design and planning using SuperPro Designer. The survey consisted of seven questions, structured to prompt reflection on key aspects, constraints, and design criteria encountered during process modeling depicted in Table 1.

Table 1. Post-course survey regarding SuperPro designer use during the course.

Question	Response Type
How did you use SuperPro Designer to dimension the bioreactor in your project? Reflect on the process you followed and indicate the key parameters you configured in the software.	Multiple choice, closed
What large-scale analysis did you perform with SuperPro Designer, and how did you ensure the process would be efficient at a large-scale?	Multiple choice, closed
How did SuperPro Designer help you identify and optimize the bioreactor's operating conditions? At the end of the list of possible answers, provide a specific example of an optimization performed in the "other" option.	Multiple choice, closed
How did you evaluate the economic feasibility of the bioprocess using SuperPro Designer? What economic factors did you consider?	Multiple choice, closed
What environmental impact of the bioprocess did you analyze with SuperPro Designer? Write in the "other" box how this influenced the design and operation decisions of the bioreactor.	Multiple choice, closed
How did you integrate product and market niche aspects into your analysis with SuperPro Designer?	Open text
What industrial property considerations (such as patents) did you take into account when planning the biotechnological project with SuperPro Designer? How did these considerations influence process development?	Multiple choice, closed

Students could select all applicable responses, and some questions included an "Other" option for free-text input. Each question and its corresponding answers were grouped into three overarching topics: *Bioreactor*

Design, Bioprocess Scale-Up, and Industrial & Regulatory Considerations. To enable a structured analysis, individual responses were further classified into conceptual subcategories within each topic. These subcategories are presented in Table 2. A detailed classification of the answers and questions is available upon request to the corresponding author.

Table 2. Post-course survey topic and conceptual subcategory division.

Bioprocess Scale-Up	Bioreactor Design	Industrial and Regulatory Considerations
Process Optimization	Bioreactor Configuration and Modes	Economic and Operational Costs
Bioprocess Fundamentals	Operational Parameters	Environmental and Sustainability Considerations
Scale-Up Strategies	Resource Management	Intellectual Property (IP) Strategy
Reactor Mode Considerations	Process Performance & Risk	No IP or Regulatory Considerations
Other	Mass & Energy Transfer Considerations	Waste management and Disposal Costs
		Regulatory and Compliance Considerations

Of the 40 students enrolled across both groups, 32 completed the survey. The survey was administered via Google Forms, and all answers were returned in textual format. For ease of quantification, a binary matrix was generated using Python to represent selections. Frequency-based metrics were used to evaluate the relative emphasis placed on each conceptual category, computed as the proportion of selections for each subcategory relative to the total number of responses within a given topic. Proficiency-based segmentation was not applied at this stage of the analysis. All code and processed datasets used for the analysis are available in the supplementary materials.

3 Results and Discussion

During the first two weeks, students underwent a full immersion in learning the characteristics of SuperPro Designer. The course began with an overview of the main menus and tools, delivered through direct instruction by the professor. The structure of the classes combined theory with practical exercises to explain the functionality of the software systematically. Additionally, students were provided with digital resources to enhance their learning experience. These resources included access to tutorials, instructional videos, and online forums (available in the supplementary material provided in the statements section). At the end of the first and second week, students were asked to complete two quizzes regarding the comprehension of the software, in the first quiz a simulation of a bioreactor for growth of *E. coli* was asked and in the second quiz a process for separation of the biomass produced in the bioreactor through centrifugation and microfiltration was asked. It was observed that from quiz 1 to quiz 2, the proportion of students reaching the proficient level increased from 44.4% to 69.4% of the population. The solid level also increased from 11.1% to 13.8%, while the basic and incipient levels diminished from 22.22% to 2.7% and from 25% to 13.8%, respectively. At the end of the first two weeks of the courses, it was observed that most of the students exhibited a competence level in SuperPro Designer in the following aspects: they became familiar with the software menus; they can define a process flow diagram; they know how to enter data for compounds, new compounds, and mixtures; they can define operating conditions in equipment such as bioreactors, centrifuges, microfiltration units, and homogenizers; and they can run simulations and analyse data. These are basic knowledge of the software corresponding to the first three steps of the smart sequence described in Figure 1. At this point, the students were ready to

improve their skills in SuperPro Designer, and they were asked to gather into teams of 3 to 4 members and complete the first activity based on a simulation of a full process for protein recovery as shown in Figure 2. This activity was completed during the third week of the course. Although the activity was discussed and developed in teams, the students were asked to deliver the main results of the simulations individually. Compared to Quiz 2, the results from the activity showed a decrease in the proportion of students reaching the proficient level (33.3%), with the rest of the students grouped into the solid level (47.0%), basic level (16.6%), and, surprisingly, the incipient level decreased to 2.7% of the students. The decrease in the proficient level can be linked to the high level of difficulty of the task. As illustrated in Figure 2, the production and recovery of a chromoprotein was used as a common task for all students and served as an evaluation tool to enhance the learning in SuperPro Designer during the third week of the course. All students performed the analysis, synthesis, and design of the studied bioprocesses, incorporating the basic stages of upstream (inoculum preparation and seed bioreactors), bioreaction (production bioreactor), and downstream (recovery and purification of the target biomolecule). It is also worth noting that this specific process was carried out on a laboratory scale during previous laboratory courses which facilitated the comprehension of the stages of the process.

For the remaining two weeks of the course, the case studies of carotenoids, lipids, and lipases production process were presented and assigned to the students, who were previously gathered in teams. For the case study of lipids, the oleaginous yeast *Schwanniomyces occidentalis* was used as a microorganism for which kinetic and stoichiometric characterization was done at a laboratory scale in a previous course. Among the main results obtained by the students during simulations of large-scale production of lipids, they proposed an inoculum development starting from 1 L bioreactor, followed by scales to 10 L and 100 L, adjusting operational parameters. Also, they use the physicochemical properties of lipids to develop a downstream process based on the extraction process for recovery and purification of lipids. From economic analysis they found that high investment and operational costs limit the process' profitability, although strategies such as selling by-products and optimizing processes are suggested to improve economic viability. Students also highlighted the importance of incorporating innovations in metabolic engineering to maximize triglyceride accumulation. The case study for lipase production aimed to design, characterize, and evaluate the economic aspects of producing a recombinant lipase for the leather tanning industry.

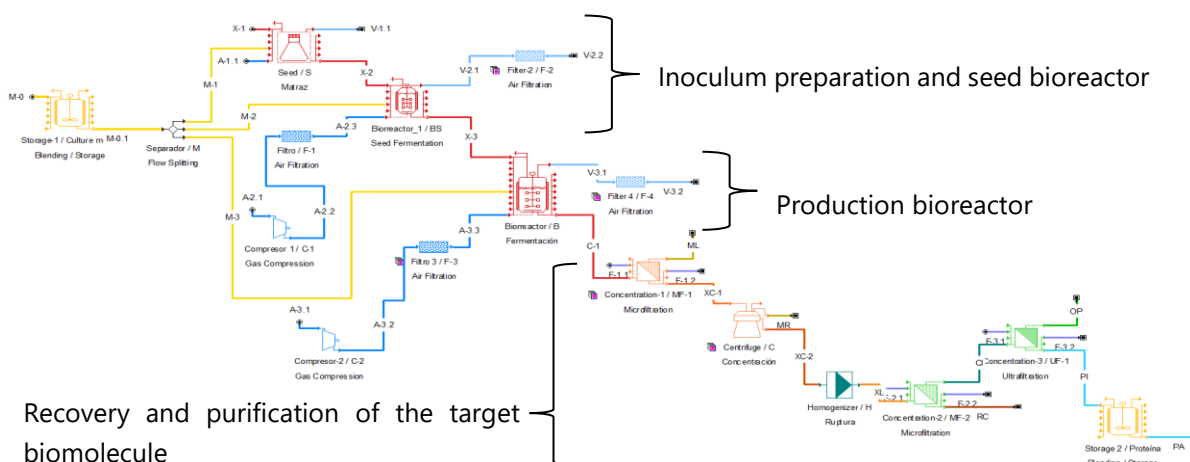


Figure 2. Typical flow process diagram obtained from SuperPro Designer. The diagram corresponds to the process for chromoprotein production and recovery.

Enzymatic tanning using lipases offers an eco-friendly alternative, yielding more uniform and flexible leather. The project proposal by the students in SuperPro Designer aimed to produce 25 tons of lipase annually using a 20 m³ main fermenter and a 2 m³ seed fermenter. Kinetic parameters were retrieved during laboratory-scale experiments by the students, as well as yields of protein recovery and purification during the downstream

process and used to simulate the stages of lipase production in SuperPro Designer, including fermentation, cell rupture, and ultrafiltration, coupled with financial analysis and logistics optimization. The scenario simulated in SuperPro by the students proved most efficient and economically viable, producing 23.7 tons of lipase per year with the highest ROI (43.4%) and the shortest payback period (2.3 years). Finally, a theoretical project was proposed for producing carotenoids using *Rhodotorula glutinis* for trout feed. A process train was designed in SuperPro Designer based on literature data. The annual demand for yeast was calculated, and the process includes fermentation in a stirred-tank bioreactor, centrifugation to separate cells from the medium, and spray drying to maintain carotenoids within the yeast cells. A simplified downstream process was chosen, producing dry yeast enriched with carotenoids as the final product. The industrial-scale bioreactor was designed considering a productivity rate, resulting in a 5622 L bioreactor to generate the necessary yeast amount. According to the results of the evaluation for the projects delivered by the students, it was found that 65.1 % of the students reached a solid level in the usage of SuperPro designer, the remaining were distributed in 17.2 % in proficient level, 13.4 % in basic level and 4.2 % in incipient level.

The results of the post-course survey are summarized in Figure 3, which illustrates the weighted frequency of selections across the three major topics related to bioprocess design: Bioprocess Scale-Up (Figure 3A), Bioreactor Design (Figure 3B), and Industrial & Regulatory Considerations (Figure 3C). Each response was categorized into conceptual subcategories to facilitate a structured interpretation of students' perceived learning outcomes following their use of SuperPro Designer. Regarding Bioprocess Scale-Up, students most frequently selected answers related to process optimization and foundational scale-up strategies. This trend suggests that SuperPro Designer was perceived as an effective tool for conceptualizing scaling challenges and opportunities for production improvement. The platform appeared to support the development of strategic thinking skills, particularly those associated with evaluating constraints and enhancing process efficiency within an industrial context. In the case of Bioreactor Design, students demonstrated high engagement with structural and operational aspects, as reflected by the strong selection of items in the Resource Management and Operational Parameters categories. This indicates that the course enabled students to grasp not only engineering considerations but also the logistical and economic implications associated with bioreactor operation. Nevertheless, *Mass & Energy Transfer Considerations* were among the least frequently selected categories. This disparity may be attributed to the limited capabilities of SuperPro Designer in modeling dynamic transfer phenomena. Since the software mainly relies on static user input rather than mechanistic calculations, an accurate consideration of these parameters requires prior theoretical knowledge and an awareness of the assumptions underlying simulation-based design.

For *Industrial & Regulatory Considerations*, the analysis revealed a strong emphasis on economic and sustainability-related factors, with relatively less attention paid to regulatory and intellectual property constraints. This imbalance may reflect students' greater familiarity with economic frameworks, as well as the non-mandatory implementation of regulatory and IP-related fields in SuperPro Designer. While the software allows users to define costs for waste disposal, assign waste streams, or incorporate royalty payments, these features are optional and often underutilized unless explicitly prompted by instructional content. Overall, the survey results suggest that SuperPro Designer effectively reinforced key engineering competencies such as process optimization, economic assessment, and scale-up planning. At the same time, the findings highlight the need to provide additional pedagogical support for underrepresented yet critical topics, including mass transfer, regulatory affairs, and intellectual property management. These areas could be better addressed through complementary teaching methods, such as targeted workshops, guest lectures, or integration with more specialized tools. This reinforces the importance of using SuperPro Designer not as a standalone solution, but as a practical component of a broader curriculum aimed at developing comprehensive bioprocess design expertise.

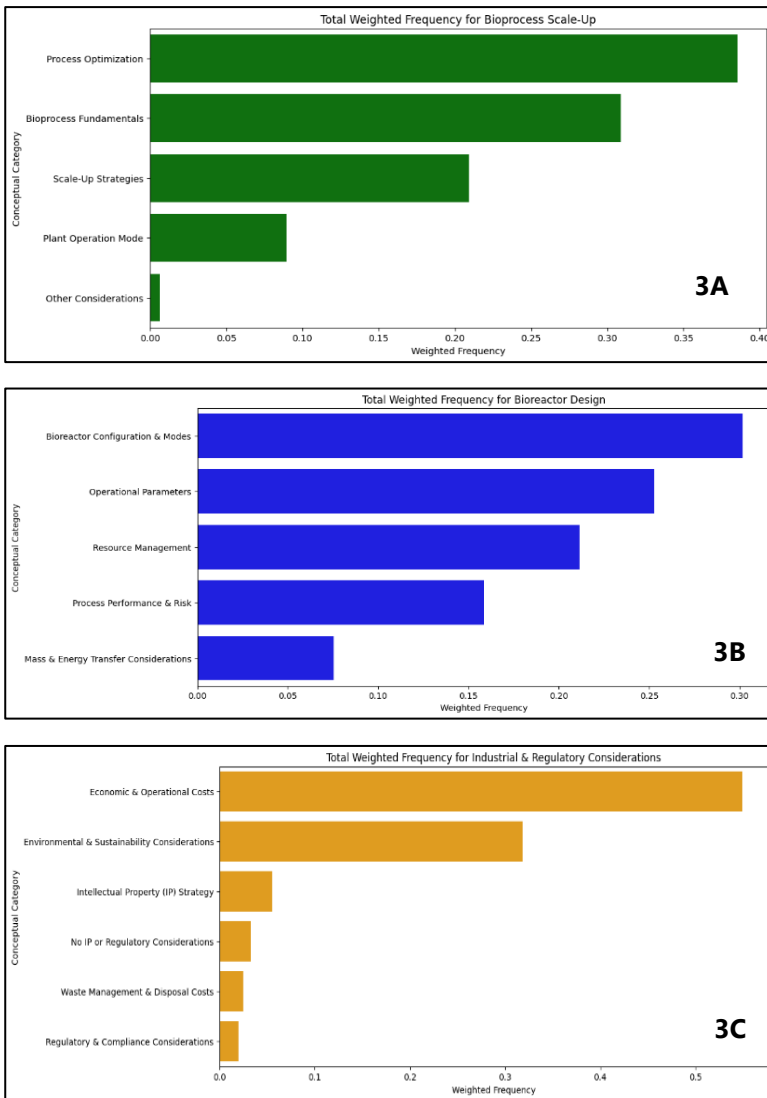


Figure 3. Post course survey results on the most relevant aspects for bioprocess design using SuperPro Designer divided by topics: Bioprocess Scale-Up (A), Bioreactor Design (B), Industrial & Regulatory Considerations (C).

4 Conclusions and perspectives

This study represents a pioneering effort in systematically integrating SuperPro Designer into undergraduate Biotechnology Engineering education. To enhance the learning experience, a structured sequence of steps was developed to guide rapid software mastery and encourage students to connect simulation with prior laboratory work. This approach enabled students to transform experimental results into robust scale-up proposals, deepening their understanding of bioprocess engineering. By embedding SuperPro Designer within a Project-Based Learning (PjBL) framework, the course fostered a hands-on, collaborative environment that mirrors real-world engineering practice. This combination not only enhanced students' technical proficiency but also developed key transversal competences such as critical thinking, autonomous learning, and strategic decision-making. The findings align with broader trends in engineering education, highlighting how structured PjBL models can promote deeper learning and better prepare students for industry-relevant challenges. Younger engineering programs seeking to strengthen simulation-based pedagogy may benefit from adopting similar integrative strategies to bridge theory, experimentation, and application.

Declarations

The authors have no relevant financial or non-financial interests to disclose. All participating students were informed at every stage of the study, and their identities remained anonymous. The research conducted only involved the collection of data from various courses where these strategies were implemented. All students participated equally in the study, and there was no differentiation in their treatment. Not any of the students' human rights were compromised. The study adhered to the standard protocols of the Tec 21 educational model of Tecnológico de Monterrey, which continuously students with challenging classes (<https://internationalfaculty.tec.mx/sites/g/files/vgjovo1851/files/tec21-model.pdf>). The study has been approved by the Department of Bioengineering at Tecnológico de Monterrey, Campus Estado de México. Publication has been authorized as an education innovation practice in the institution.

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Using a Chatbot for Student Onboarding and Learning in Projects: Technology as an Enabler of Active Learning

Erik T. Lopes¹, Yasmim Bezerra Oliveira Altoé², Pedro Gonçalves Prazeres², Luiza Oliveira de Araujo², Simone Borges Simão Monteiro², Diana Mesquita³, Jens Myrup Pedersen⁴, Rui M. Lima¹

¹ ALGORITMI Centre, Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal

² Department of Production Engineering, University of Brasília, Brasília, Brazil

³ Universidade Católica Portuguesa, Faculty of Education and Psychology, Research Centre for Human Development, Porto, Portugal

⁴ Cyber Security Group, CMI Section, Department of Electronic Systems, Aalborg University, Copenhagen, Denmark

Email: erik.lopes@algoritmi.uminho.pt, bezerrayasmim7@gmail.com pedroprazeres98@yahoo.com.br, loliveiradearaujo647@gmail.com, simoneborges@unb.br, dmesquita@ucp.pt, jens@es.aau.dk, rml@dps.uminho.pt

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Abstract

Using technologies as enablers of active learning methodologies is a recurring topic in the scientific literature. Various tools have been developed and applied in engineering education, yielding promising results. The rapid development and widespread adoption of generative artificial intelligence (AI) language models have recently sparked discussions on their use, regulation, and evaluation in the teaching and learning process. Chatbots represent a relevant application, offering opportunities such as enhancing the learning process, providing rapid and personalised access to knowledge, and enabling iterative support that benefits students. Additionally, chatbots can be applied in administrative and support activities, potentially reducing faculty workload, which is one of the challenges in adopting active learning approaches. Given this, this article presents a method for developing a chatbot using low-code tools to accelerate the onboarding process for the Erasmus+ Egalitarian project, which focuses on solid waste management and waste pickers. Organised into iterative cycles, this project has already engaged students of various nationalities, addressing challenges related to initial problem contextualisation, knowledge management, and the diverse concepts and tools adopted. Thus, students and faculty members who participated in the first three cycles of the project evaluated the developed tool, highlighting strengths and areas for improvement and comparing their experiences with and without the chatbot. The results indicate the feasibility of chatbot development without requiring programming skills, the potential of generative AI to provide fast and direct access to knowledge, and an improved experience for participants in projects involving active learning. Finally, this tool enables gradual and iterative training throughout the project cycles, reducing the effort required from faculty members and experienced students in the onboarding process in each new cycle.

Keywords: Active Learning; Engineering Education; Project Onboarding; Chat Bot; Project Management.

1 Introduction and Theoretical Background

The rapid pace of technological advancement, primarily driven by developments in generative artificial intelligence (AI), significantly transforms the global labour market and redefines the skill sets required from professionals (Ellingrud et al., 2023). According to the Future of Jobs Report 2025 by the World Economic Forum (2025), it is estimated that by 2030, approximately 86% of surveyed organisations expect AI-based and information processing technologies to cause structural changes in their business models. This transformation goes beyond the production sector, directly affecting education and requiring innovative pedagogical approaches aligned with the demands of the so-called Industry 4.0 (Führ, 2022). In this context, Education 4.0, and even Education 5.0, emerge as frameworks designed to prepare individuals for highly technological, collaborative, and dynamic environments, while also fostering the development of learning ecosystems and a strong sense of responsibility (Alharbi, 2023). Incorporating tools such as artificial intelligence, digital platforms, and methodologies based on experimentation and projects (learning by doing) is an effective strategy to promote the development of skills aligned with the dynamics of an increasingly automated and connected world (Führ, 2022). According to Bartolomé et al. (2018), two fundamental principles of Education 4.0 are

personalisation and flexibility, which allow students to adapt their learning paths to their own rhythms, styles, and needs.

Higher education institutions are a key pillar in preparing professionals to face contemporary challenges. In this context, traditional teaching models are being replaced by student-centred approaches that promote personalised learning. Active learning fosters essential competencies such as creativity, autonomy, and critical thinking (Murillo-Zamorano et al., 2021). Strategies like Problem-Based Learning (PBL) and Project-Based Learning (PjBL) enhance student engagement through real-world challenges and the development of tangible solutions (Marnewick, 2023). These methodologies can significantly improve learning outcomes when combined with the purposeful integration of digital technologies (Krull & Duarte, 2017). However, there are challenges, such as increased workload, students' insecurities and engagement, and demanding teachers to develop skills, including the use of new technologies, empathy and feedback (Das Neves et al., 2021).

Low-code/no-code development platforms (LCDPs) have emerged as strategic tools, enabling individuals without detailed technical knowledge to create functional digital solutions. Combining these platforms with generative AI technologies expands the possibilities for innovation, encourages agile application development, and democratises access to the creation of adaptable and scalable educational tools (Sido & Emon, 2024). Among the most promising technological solutions in this scenario are chatbots, defined as computer systems that interact with users through natural language, offering personalised support for learning and communication (Hwang & Chang, 2023). In addition to optimising knowledge management, recent studies have demonstrated their potential as pedagogical assistants, providing both student support and reducing teachers' workload by answering frequently asked questions and offering continuous guidance (Pérez et al., 2020). In this context, ensuring access to technology for all students, training the educators and allowing the configuration of the agents without the need for programming skills are some of the existing challenges (Ramandanis & Xinogalos, 2023; Rooein et al., 2022).

Based on these premises, this article proposes a method for developing a chatbot using low-code/no-code tools to support the onboarding process of students in the Egalitarian project, an initiative of the Erasmus+ program. This initiative aims to develop digital solutions for solid waste management and improve working conditions for waste pickers in the Federal District of Brazil. The project brings together students and faculty from different countries and academic fields and is structured around iterative cycles, which demand effective strategies for integrating and transferring knowledge among participants (Egalitarian, 2025). The developed chatbot addresses recurring challenges such as initial contextualisation, knowledge integration, and information transfer between project cycles, contributing to a more efficient and sustainable educational experience. The proposal explores the potential of chatbots as support tools for active and collaborative learning, detailing the development process, user perceptions, and benefits observed during the initial cycles of the initiative.

2 Methodology

This paper is an exploratory case study applied in the context of the Erasmus+ Egalitarian Project. A case study is an empirical approach that gathers data from a specific system and analyses it in depth (Gil, 2002). Its goal is to deepen understanding of a problem and develop related hypotheses and theories (Mattar, 2005). In the development of chatbots, numerous stages can be identified, which should be adapted according to the complexity level, objectives, and tools used (Lopes et al., 2024). Therefore, this study followed the six-step approach from Lopes et al. (2024). Table 1 summarises the methodological approach and decisions in each step.

Table 1. Methodological Approach. Source: Developed by the authors.

Step	Main Definitions
Initial analysis	- Software Choice: Microsoft Copilot has been selected due to its license availability within universities, minimal technical expertise requirements, and ease of implementation. - Context: The chatbot will support the onboarding process for the Egalitarian Project. It will assist staff and academic personnel in providing key information to new students involved in each project cycle.
Definition of characteristics	- Tone and Accessibility: The chatbot will adopt a friendly, non-technical tone. It will be publicly accessible to all project participants and the wider public, without needing authentication. - Response Style: Responses will be concise and direct, offering further details upon user request. - Information Management: The chatbot will limit its responses to publicly available information and will be programmed to avoid sharing sensitive or unpublished data. - Languages: While English will be the primary language, the chatbot will also offer support in Portuguese, Dutch, and Danish to accommodate the linguistic diversity of project participants.
Design	- Introduction: Upon activation, the chatbot will provide a brief overview of the Egalitarian Project, its objectives, and limitations. It will also include a link to the project feedback survey. - Project Information: The chatbot should provide details about the Egalitarian Project, including participating universities, project cycles, and organisational structure. - Context on Waste Pickers: The bot should be able to explain the challenges faced by waste pickers and the broader waste management issues in Brasília, offering examples and relevant data. - Project Activities: The chatbot will present information about programmes and initiatives under the Egalitarian Project to inform students about ongoing and past activities. - Redirect and Support: In cases where the chatbot cannot address a specific query, it will provide appropriate contact details for further assistance.
Implementation	- Technical Development: Chatbot development may include using Microsoft Power Virtual Agents, with customisable flows, triggers, and actions tailored to specific user needs. - Model Configuration: A standard large language model (LLM) will be used, without internet access, to reduce the risk of hallucinations and misinformation. - Language Support: English will serve as the default language, with additional support for Portuguese, Dutch, and Danish, aligning with the project's international context. - Privacy and Authentication: No user authentication will be required, though the chatbot will be designed to handle private matters cautiously and appropriately. - Training Resources: The model will be trained using PDF and text-based documents, particularly those related to the Egalitarian Project's official resources and guidelines.
Testing	- Synchronous: A session with students from the Egalitarian Project Management Office at the University of Brasília will be conducted. - Asynchronous: An online survey will be distributed to students, supervisors, and professors involved in the project's current and past cycles.
Evaluation	- Data Analysis: Responses will be analysed through both quantitative and qualitative methods. - Interviews: Informal interviews will be conducted with selected participants, primarily from the Project Management Office and the University of Minho.

3 Results

The chatbot “Naira” was developed using Microsoft’s Copilot tool, a generative artificial intelligence solution integrated into low-code development platforms. Naira was designed as a virtual assistant for the Erasmus+ Egalitarian project to facilitate the onboarding process for students and other participants. Figure 1 illustrates the Studio interface, highlighting its user-friendly language and the adopted conversational format. The development process is simplified, resembling a conversation with a chatbot. It involves providing general information and adding instructions and sources of knowledge into specific fields. Naira’s development followed the six methodological steps described in this article: initial analysis, definition of characteristics, design, implementation, testing, and evaluation. This structured sequence of activities enabled the creation of a functional solution without requiring advanced programming skills.

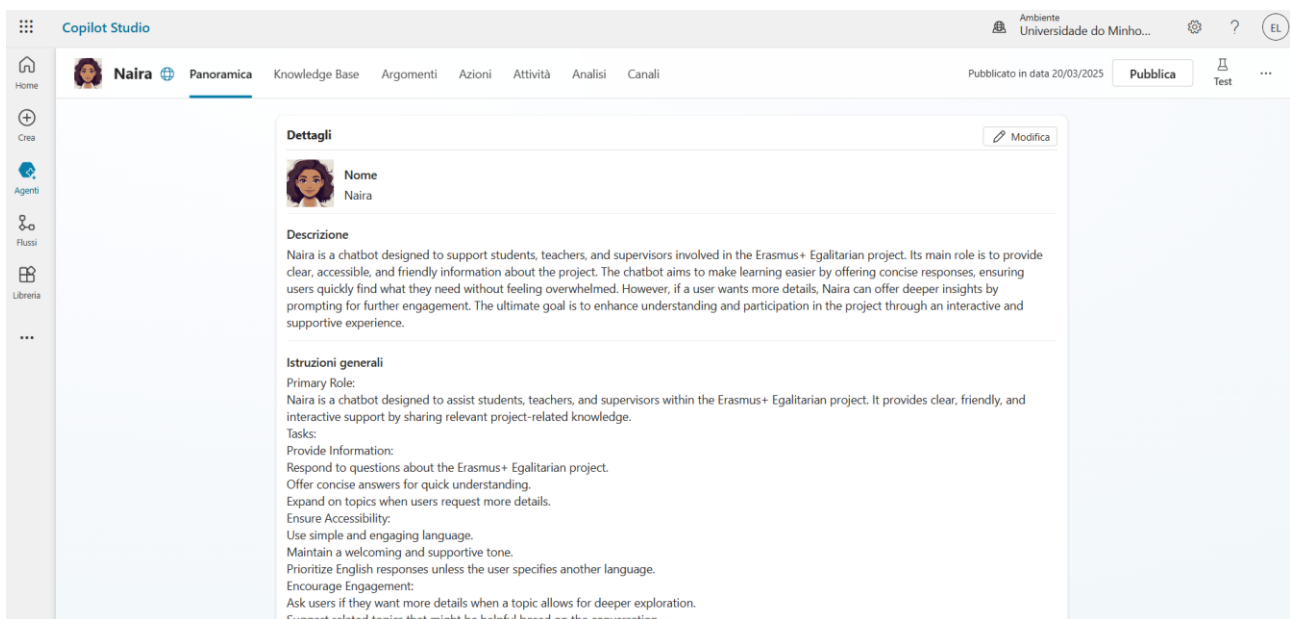


Figure 1. Copilot Studio overview. Source: Developed by the authors (2025).

In the initial analysis phase, the team identified the main doubts and difficulties faced by participants during previous project cycles. Based on this information, the chatbot’s development was guided by a focus on accessibility, natural language interaction, and multilingual support. Naira’s design emphasised an intuitive conversational interface, with dialogue flows designed to simulate a humanised and friendly interaction. Using Microsoft platforms, the team organised knowledge blocks by topic, linked to a knowledge base constructed from project documents, support materials, and FAQs. Copilot was employed to refine these conversational flows through AI-generated suggestions, streamlining the development process and enhancing the coherence and naturalness of the responses. Figure 2 presents the prototype interaction with the user.

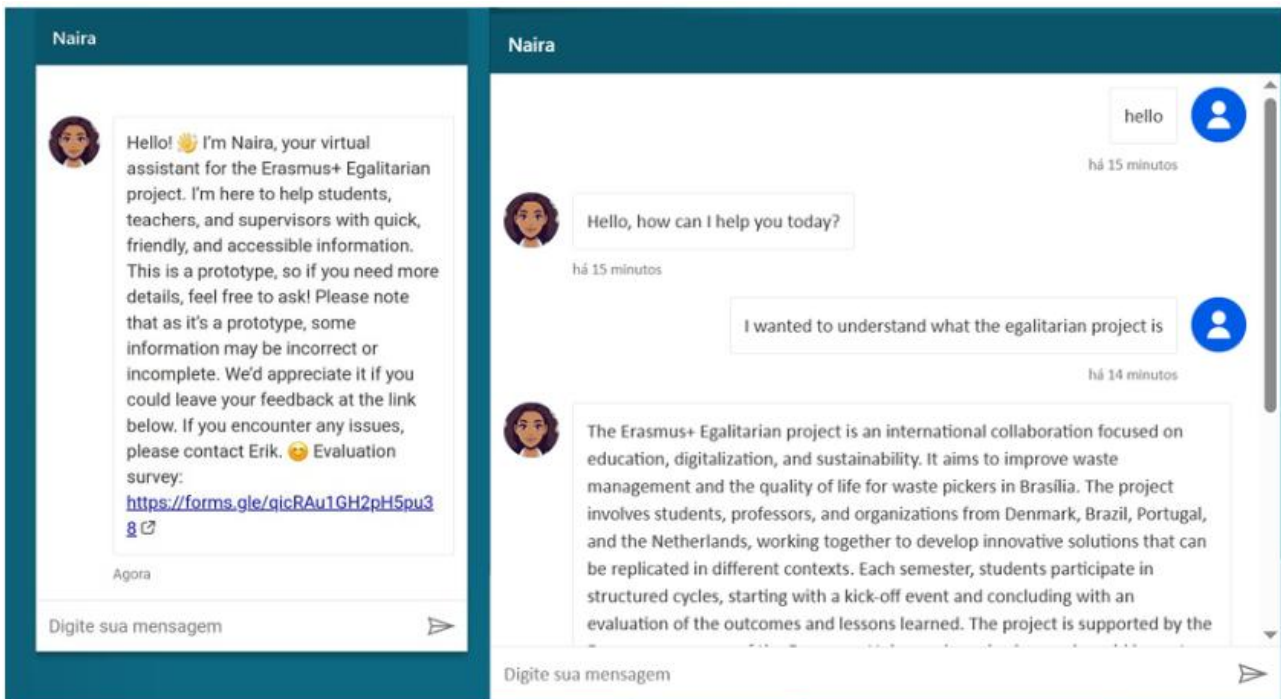


Figure 2. Naira chatbot interaction. Source: Developed by the authors (2025).

During the implementation phase, usability tests were conducted with pilot groups, leading to adjustments in question triggers and improvements in response accuracy. The final stage involved applying a feedback form regarding the chatbot's use. This evaluation aimed to assess its usability, educational and informational value, and impact on understanding the project's social context. The responses were collected through a Likert scale ranging from 1 to 5 and organised into three respondent groups: Total Participants (n=23), Teachers/Supervisors, and Students/Others. This segmentation allowed for observing both the general perception and potential variations in the experience across different user profiles involved in the Egalitarian Project.

4 Discussion

Overall, the scores presented in Figure 3 indicate a very positive evaluation of the chatbot, with most items reaching averages close to or above 4.5. These results suggest that the tool adequately fulfilled its role as a support instrument for active learning and the onboarding process of new participants. Among the highest-rated items are: "Recommend using Naira to other students and professionals that want to understand Egalitarian better" (4.95), "Could help people understand faster and better aspects related to the Egalitarian Project" (4.86), and "Adds value to project-based learning experiences by supporting students with useful information in an interactive way" (4.86). This also demonstrates the interest of both students and teachers in the use of new technologies in education, signalling opportunities for research that follow this direction. The synergy between new technologies and active learning had previously been highlighted (Lima et al., 2023; Souza & Debs, 2024), representing a potential alternative for increasing engagement in both curricular and extracurricular initiatives.

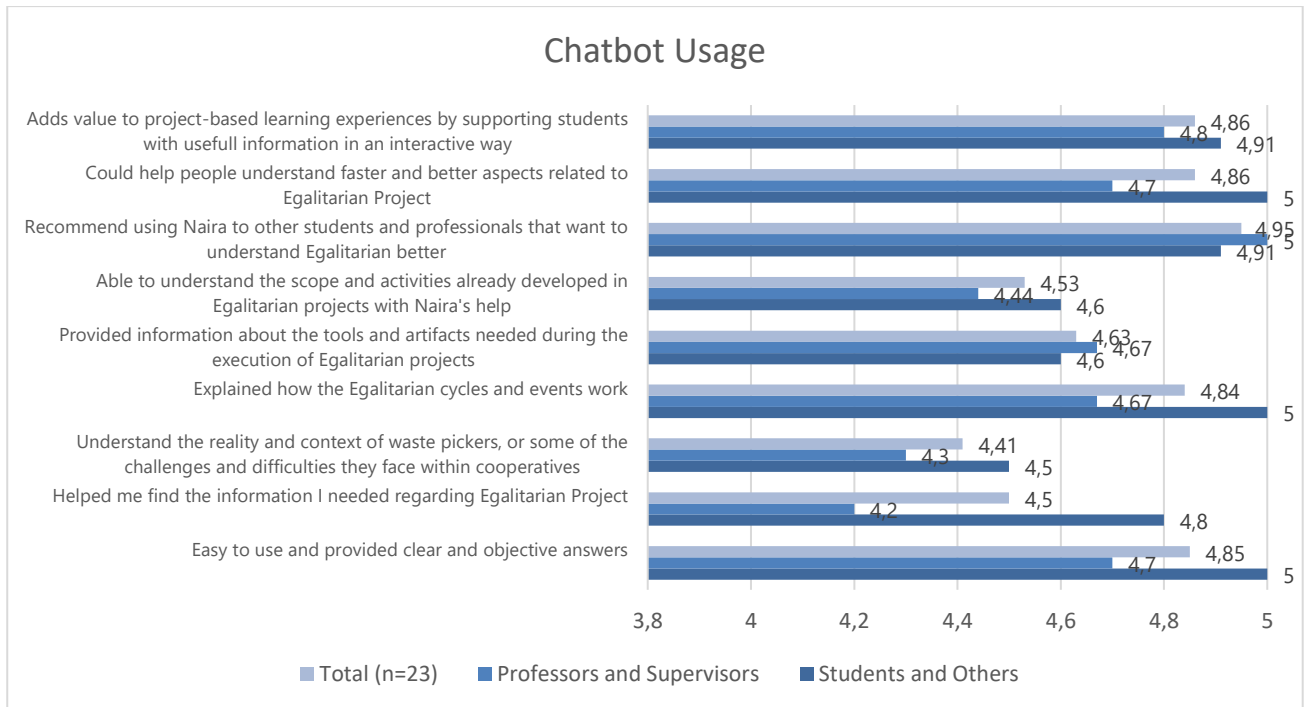


Figure 3. Results Related to the Use of the Chatbot. Source: Developed by the authors (2025)

In contrast, the items with the lowest averages were “Understand the reality and context of waste pickers, or some of the challenges and difficulties they face within cooperatives” (4.41) and “Helped me find the information I needed regarding the Egalitarian Project” (4.5). The relatively lower evaluation regarding understanding waste pickers' reality may be associated with limitations of the language model used in the chatbot. More complex social issues, such as the challenges faced by waste pickers, require sensitivity, context, and appropriate language. These aspects are not always fully represented in the knowledge bases that support the chatbot's functionality, which may compromise the depth and nuance of the responses generated. Moreover, there may be a limitation regarding the content used to train the chatbot, with less specific information, as mainly public documents were utilised for this topic. Incorporating additional sources of knowledge, pre-processing the documents prior to training the model, or enabling internet connectivity so that the model itself can locate further references may be considered alternatives to enhance the quality of the responses.

A notable discrepancy between the groups was observed in relation to the effectiveness of finding information about the project. While students gave an average score of 4.80 to the item “Helped me find the information I needed regarding the Egalitarian Project,” teachers/supervisors gave a significantly lower score of 4.2. This difference may reflect varying expectations between user profiles. Teachers and supervisors, being more familiar with the project's content, tend to seek more detailed or analytical answers. At the same time, students and other participants likely value the clarity, objectivity, and accessibility of the responses more. This may prompt discussions regarding the extent to which the chatbot should be generalist or specialist, potentially leading to modifications during the solution design phase. In this context, one option would be to create specific agents for distinct project topics: a chatbot dedicated to the waste picker context, another for completed projects, and a third for operational and management aspects. Although this alternative increases the workload, it allows for a more explicit structuring of user personas, which could be explored in future research.

Finally, the scope of interaction and the time spent using the chatbot seem to have influenced respondents' perceptions. Users who interacted more superficially or with overly generic questions may have had a less accurate experience, directly impacting the evaluation of the tool. This hypothesis is supported by the fact that 12.56% of responses marked the option "Not Applicable," indicating that some participants likely did not use the chatbot enough to provide a well-informed evaluation. This option also suggests that some interactions may not fully explore the features and functionalities offered, potentially contributing to less accurate or informed assessments. Again, this may indicate that the chatbot covers too many topics without providing sufficient detail on the subjects it addresses. Therefore, managing users' expectations regarding the depth of content during its presentation is essential.

5 Conclusion

The article presented the development and application of a chatbot in the context of the Egalitarian Erasmus+ project to assist in onboarding new participants throughout the development cycles. The creation of the tool became necessary due to the high turnover of students during the development periods and the need to optimise the process of introducing information to new entrants. Thus, the chatbot was structured to provide information about the context of the projects: solid waste management systems with a focus on recyclable material cooperatives, the context of the projects currently under development, and the processes of each cycle of the Egalitarian Project.

Applying the six-step methodology highlighted the importance of systematisation in building a low-code/no-code chatbot in a limited programming and development environment. Coupled with the chatbot, the use of artificial intelligence (AI) provided a personalised learning experience at the beginning of the cycle, allowing for an adequate understanding for each student and teacher according to the context they experienced.

Additionally, the results demonstrated the potential of the solution in the Egalitarian project and the tool's effectiveness for the students and teachers involved. Among the positive aspects observed, it is worth highlighting the recommendation of the Naira chatbot to other students and teachers who wish to learn more about the project, which shows the importance of using the tool to understand the initial context. In contrast, the implementation of the tool revealed limitations of the solution both in relation to the users and the tool itself. For example, users had limited time to interact with Naira, the solution was applied with a limited number of participants, and contextualising documents were created to ensure the effectiveness of the responses. To provide more accurate results, it is necessary to repeat the described methodology, align the chatbot's objective with the participants, ensure more interaction time with the solution, and add more content to the chatbot to ensure the effectiveness of the responses.

Therefore, this study contributes to the understanding and application of chatbot solutions in the context of active learning for Engineering. Future approaches could improve the chatbot's capabilities to personalise according to the user's knowledge level and the ability to provide more complex answers. Additionally, it could include integration with other solutions such as Microsoft Power Virtual Agents, Teams, and SharePoint.

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Analysis of the production system of a corrugated board company

Ana Margarida Felgueiras¹, Andreia Bargas¹, Bárbara Oliveira¹, Dinis Carvalho¹, Eduardo Silva¹, Francisca Abreu¹, Igor Subtil¹, Inês Ferreira¹, Maria João Ferreira¹, Teresa Leite¹

¹ ALGORITMI Centre, Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal

Email: margfelgueiras2013@gmail.com, b.andreia2003@gmail.com, ba.oliveira03@gmail.com, dinis@dps.uminho.pt, eduardogil.csilva@gmail.com, francisxaguiseabreu@gmail.com, igorsubtil03@gmail.com, ines.sferreira03@gmail.com, mariajoaoferreira2003@gmail.com, teresateixeira280903@gmail.com

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Abstract

This project was developed within the framework of Project-Based Learning (PBL), with an emphasis on solving real-world problems and improving the performance of industrial processes. Carried out at a cardboard company (SMSA), in collaboration with the company's Continuous Improvement manager, the project's main focus was on improving the operational efficiency of the entire industrial process. The main objective was to identify bottlenecks in the flow and increase its capacity. Through an in-depth assessment of several processes in various sections, we identified the palletising and packaging unit as the main bottleneck. The inconsistent time recording data provided by the company posed a significant challenge in the analysis. To overcome these obstacles, we had to collect data in the field and carried out simulations of different operational scenarios to evaluate potential improvements and propose data-based solutions. This project emphasises the role of systematic analysis in enhancing industrial processes, demonstrating how a structured, data-driven approach can generate measurable operational benefits. By increasing the efficiency and capacity of the palletising and packaging unit, our results not only contribute to better operational performance at SMSA but also illustrate the practical applications of the PBL methodology in solving complex industrial challenges.

Keywords: Project-Based Learning (PBL), Corrugated Cardboard Industry, Bottleneck, Production System

1 Introduction

The Project-Based Learning (PBL) methodology has been widely applied in Engineering and Industrial Management education, fostering active learning by challenging students to solve real-world problems in authentic organizational contexts. At the University of Minho, PBL has been implemented successfully for over a decade, leading to significant development of both technical and transversal skills, including teamwork, critical thinking, and problem-solving (Barros et al., 2017; Lima et al., 2007). This educational approach enhances the connection between academic knowledge and practical application, preparing students for the complexities of modern industry.

Within the industrial environment, one of the key principles for continuous improvement is creating flow, as emphasized by Lean Thinking. This principle focuses on reducing delays, eliminating waste, and ensuring a smooth progression of materials and information throughout the production process. A crucial tool for implementing this principle is Value Stream Mapping (VSM), which provides a visual representation of the flow of materials and information and helps identify bottlenecks and inefficiencies. Studies developed at the University of Minho, such as Dinis-Carvalho et al. (2019), have shown how VSM can be applied in real industrial settings to identify waste and support Lean transformations and decision-making.

It was in this educational and methodological context that the present project was developed at SMSA – Indústria de Embalagens, as part of the academic curriculum of the Master's Degree in Industrial Engineering and Management at the University of Minho. The project integrated knowledge from key subjects such as

Process Modeling and Analysis, Advanced Organization of Production Systems, and Industrial Project Management.

The project was motivated by the identification of bottlenecks in the production flow of SMSA. Afterwards, a bottleneck was identified in the packaging area, where an excessive accumulation of inventory and prolonged queues led to substantial delays and frequent interruptions in palletizer operations. In response to this challenge, SMSA made a significant investment in a new packaging machine, aimed at standardizing the lines and improving production flow.

Therefore, the main goal of this project was to identify, address, and optimize inefficiencies in the production flow of SMSA, focusing on the packaging department where the bottleneck was identified, by projecting the benefits of the recent investment and exploring alternative supply scenarios through simulation. This simulation was built using real company data to provide an accurate and reliable basis for analysis and decision-making.

To ensure the effectiveness of the project, a structured PBL (Problem-Based Learning) approach was followed. The team held bi-weekly meetings, both in person and online, with company stakeholders and academic supervisors. Industrial project management tools were employed to guide the development process and monitor the project's progress in line with its objectives. Studies, such as the one by Carvalho et al. (2018), highlight the effectiveness of PBL in solving real industrial interdisciplinary problems and fostering cooperation between academia and industry.

Throughout the project, the team encountered several personal and academic challenges, which required resilience, adaptability, and a commitment to structured problem-solving. Despite these obstacles, the project produced relevant and applicable results, benefiting both the company and the student team. The integration of real-world data into a simulation model proved fundamental in supporting data-driven decisions that enhanced operational efficiency and financial performance.

In the following chapters, the challenges encountered, the methodologies applied, as well as the creation of various scenarios, in which determining factors such as the introduction of a new machine, varying the capacity in the rotation and the addition of a sensor in the mats were taken into account, will be analyzed in detail. The results achieved will also be explored, contributing to a comprehensive understanding of the proposed solutions and their impact on SMSA's production system.

2 Project Development

The project was developed following a Project Based Learning (PBL) approach, whose purpose is for learning to occur through investigation and resolution of practical challenges, in a business context. At the University of Minho, the strategy is to encompass the course's various Curricular Units in a complex and challenging project, where students are encouraged to find viable solutions based on a real context, promoting more captivating and meaningful professional development. The project in question was carried out at Sebastião e Martins S.A. (SMSA), a medium-sized company in the corrugated cardboard sector, where the curricular units of Process Modelling and Analysis and Advanced Organization of Production Systems provided fundamental knowledge to fulfil the main objective, the improvement of the company's production flow. At the same time, studies were carried out in the area of ergonomics and human factors, which will not be the focus of this article.

With regard to Industrial Project Management, tools such as the RASCI matrix and MS Project were used to guide and monitor the development of the project, ensuring that it followed the initial planning and remained within the established deadlines.

The team was made up of nine members, supervised by two advisors, a teacher and a company representative, which involved consistent organization throughout the semester. Two weekly meetings were defined, one focused on planning and distributing tasks and the other dedicated to carrying them out, normally at the company's headquarters. In addition, several communication channels were used, including WhatsApp, Google Drive and Slack, aiming at informal contact, storing information and exchanging ideas and feedback with teachers and supervisors, respectively.

During the project development phase, the team faced several challenges, requiring adaptability and continuous effort from both parties. One of the main obstacles was coordination with the other curricular activities of the semester, given the size and demands of the project. At the same time, some difficulty was felt in defining the problem, given the scope of the proposed objective, followed by some lack of motivation on the part of the team in this initial phase. Finally, naturally, obstacles were encountered in the search for a solid and sustainable solution, namely in the collection, acquisition and interpretation of data.

Despite the difficulties experienced, significant results for the company were achieved, as well as personal/professional goals for the team members. The content taught throughout the Industrial Engineering and Management course was consolidated through the practical application of concepts, providing in-depth learning. Not only were technical skills developed, but also transversal skills were reinforced, such as teamwork, time management and decision-making based on real data.

The Project-Based Learning (PBL) methodology structured the development and implementation of the project, establishing a strong connection between academic knowledge and industrial reality. Engagement with a real-world production challenge facilitated the development of technical skills in production flow analysis, simulation modelling, and lean principles. Simultaneously, the iterative and collaborative nature of PBL encouraged critical thinking, autonomy, adaptability, and informed decision-making, aligning with core pedagogical goals such as interdisciplinarity and reflective learning.

The final proposed solution was based on a simulation of the production system, where real data measured on the ground by the team was inserted. This simulation supported the proposal, demonstrating measurable improvements in both operational and financial KPIs, which is the project's major milestone.

3 Analysis of the production system - methodology

3.1 Bottleneck Identification

Analysing a company's production flow is essential to identify bottlenecks and optimize processes, increasing efficiency and ensuring the strategic use of available resources (Rogowska, 2018).

This chapter not only identifies the main bottleneck in SMSA's production system but also provides a comprehensive overview of the company's production flow. Understanding this overall structure is key to contextualizing where inefficiencies arise and how they affect the performance of the system as a whole.

In the SMSA production system, the process begins at the corrugating machine, where paper rolls are transformed into corrugated cardboard. This intermediate product is then directed to specialized machines that shape it into boxes or plates. Next, the product batches are transported by an automatic conveyor to the palletizing, strapping, and wrapping stages. SMSA's main final products are boxes and plates.

To gain a clear understanding of SMSA's production dynamics, the entire flow was directly observed over an extended period, enabling a detailed assessment of machine interactions and operational rhythms. Through this observation, it became evident that the buffer located before the palletizing stage was frequently operating

at full capacity. As a result, the automatic conveyor was often unable to collect new batches, forcing upstream production lines to stop. These interruptions led to significant productivity losses and operational inefficiencies, highlighting this area as the system's main bottleneck.

This constraint stems from the limited capacity of the system downstream of the palletizer, which processes all factory products, both boxes and plates. To further analyse and visualize this constraint, the production flow was simulated using SIMIO, a discrete-event simulation software widely used in manufacturing systems modelling (Sepúlveda et al., 2016). A picture illustrating this process is provided below.

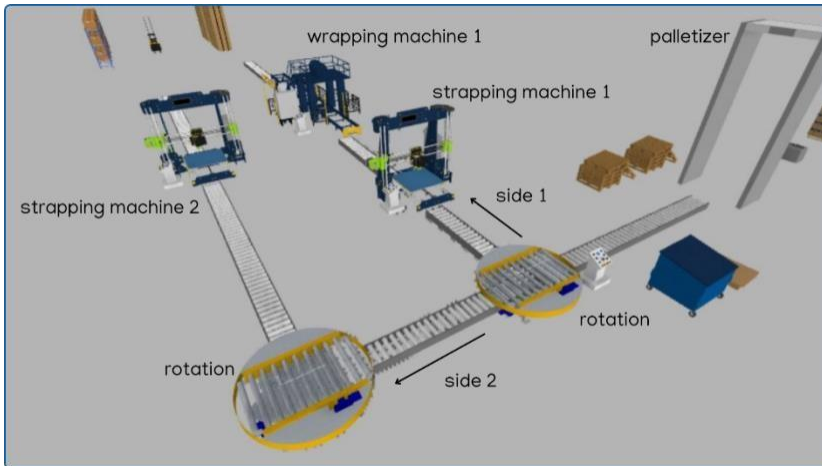


Figure 1: Production flow after the palletizer

Figure 1 illustrates the system after the palletizing stage, highlighting the two processing sides: side 1, where most of the production flows, and side 2, dedicated exclusively to plates. Due to the specifications of strapping machine 2, plates can only be processed on side 2. The key machines involved, palletizer, strapping machines, and wrapping machine, are labelled for clarity.

Another critical issue identified was the low utilization of the strapping machine on side 2, which is dedicated exclusively to batches of plates. Since plates account for a small share of total production, this machine remains underutilized, while the strapping machines on side 1 frequently experience overload due to the high volume of box production. This imbalance further contributes to inefficiencies in the system after palletizing.

3.2 System after palletizer

The post-palletizing production system is a critical stage, as it determines the routing of products based on their type. For plates, the flow is relatively straightforward: after palletizing, they proceed to the first rotation and are directed to side 2.

On the other hand, boxes follow a different trajectory but still face constraints. All box batches are routed to side 1, where they undergo strapping. However, boxes are categorized into two types: with and without a turn. This classification depends on the pallet's orientation and the adjustments needed for proper alignment.

Turn-based boxes benefit from a more efficient flow, as they enter the first rotation in the correct position, allowing them to proceed directly to strapping machine 1 without requiring additional movement. In contrast, non-turn boxes require a longer process, they must enter the rotation, advance up to halfway, and complete a full turn to align the pallet before being transferred to the conveyor leading to strapping machine 1.

Additionally, between the palletizer and the first rotation, as well as between the first rotation and strapping machine 1, the conveyor belts are equipped with two sensors, allowing two pallets to occupy each section simultaneously. This strategic solution aims to optimize product flow, particularly during periods of high occupancy. If the subsequent operation (such as rotation or strapping) is in use, the sensors allow two batches

to temporarily wait on the conveyor belt before moving forward. This buffering mechanism helps minimize flow disruptions and provides greater operational flexibility, although it does not entirely eliminate the risk of blockages if the downstream resources experience excessive occupancy times.

The current system was modelled in SIMIO, allowing its comparison of the results obtained with the different scenarios created. Table 2 shows the values of the metrics analysed in a 24-hour time interval.

Table 1: KPI's results of the current scenario

Current Scenario	
Output	2053
Palletizer Block Rate	14.6%
1st Rotation Block Rate	2.6%

Overall, the current system configuration reflects a well-structured production logic, yet it faces significant challenges, particularly in optimizing trajectories and minimizing unproductive times. The design and integration of alternatives or improvements, such as the redistribution of trajectories or modifications to equipment, are crucial to enhancing overall efficiency and addressing the identified bottlenecks.

4 Study and comparison of different scenarios

Throughout the study, several scenarios were developed and analysed with the goal of optimizing the production system, ensuring the technical and operational feasibility of each proposal. These approaches aim to provide practical and effective solutions to the challenges identified within the production chain, promoting more efficient resource management and improving overall performance. Different configurations were explored to optimize the flow of materials, taking into account the existing limitations and opportunities within the factory. Given that the company is planning to install a new wrapping machine on side 2, this change was incorporated into the scenario development, allowing the boxes to be processed on both sides. However, the plates will only be routed to side 2 due to the specifications of the strapping machine, unless explicitly stated otherwise in the scenarios.

The first scenario proposes the use of only turn-based boxes, which are primarily directed to side 1 to make optimal use of the caterpillars. However, if side 1 reaches full capacity, the boxes can be diverted to side 2. This scenario is designed to maximize the utilization of the caterpillars, thereby enhancing the efficiency of the transport process.

The second scenario envisions the coexistence of "turn" boxes, non-"turn" boxes and plates. In this case, the plates are restricted to going exclusively to side 2, while the boxes, upon reaching the first rotation, can choose their destination, side 1 or side 2, based on rotation times and the availability of the subsequent machines. This approach provides greater flexibility in the system, allowing for dynamic decision-making to optimize the flow of materials.

In the third scenario, the inclusion of the ability to add corner protection in strapping machine 1 is considered. This change allows the plates, which were previously restricted to side 2, to also be processed on side 1. As a result, any product, upon reaching the first rotation, can choose the most suitable destination based on the availability of the subsequent machines.

In the fourth scenario, priority is given to passing non-"turn" boxes, which go directly forward at the first rotation, as the passage time is significantly shorter compared to directing them to side 1. However, if the direct

flow becomes congested, the boxes can be redirected to side 1. This approach aims to optimize flow efficiency while maintaining flexibility to manage potential bottlenecks.

Finally, the fifth scenario proposes the exclusivity of non-"turn" boxes, which preferentially go forward at the first rotation, using the most direct path to side 2 due to the lower complexity of transport. However, in cases of congestion on side 2, the boxes can be redirected to the opposite side.

In addition to these scenarios, the possibility of entering two batches simultaneously in the first rotation, provided they belong to the same order, was explored as a viable option. Furthermore, the study considered the installation of an additional sensor on the conveyor belts between rotations, as well as between the second rotation and strapping machine 2, and also the combination of these two elements.

These scenarios were analysed in detail, considering the impact of each configuration on the performance of the production system, particularly in terms of resource utilization. The best results of each scenario were achieved when the entry of two batches in the first rotation was combined with the installation of an additional sensor on the aforementioned belts, allowing them to accommodate two products simultaneously. Table 2 presents the optimal results of the different scenarios, enabling a detailed comparative analysis of the production system's performance under varying operating conditions.

Table 2. Scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Output	2239	2258	2265	2169	2175
Palletizer Block Rate	6.30%	6.17%	6.11%	9.56%	8.11%
1st Rotation Block Rate	1.85%	0.69%	0.74%	0.51%	1.56%

Table 2 highlights a clear performance advantage for scenarios 1, 2, and 3, all of which achieve output values above 2,200 units while maintaining palletizer block rates close to or below 6.3%. Among these, scenario 3 shows the best overall performance, with the highest output and lowest palletizer block rate, suggesting the effectiveness of equipment upgrades. Conversely, scenarios 4 and 5 display lower productivity and higher block rates, reflecting the limitations of less flexible routing strategies. However, it is important to consider the implications and requirements associated with each of these scenarios to make a comprehensive comparison. Scenario 1 requires an additional investment in pallet rotation mechanisms to ensure that all pallets enter the palletizer with the same orientation. On the other hand, Scenario 3 necessitates an upgrade to the strapping machine located on side 1, replacing it with a more advanced version equipped with corner placement functionality. This upgrade would allow the machine to strap both boxes and plates, enhancing flexibility in the production process.

In Scenario 2, a hypothetical situation was tested in which the buffer size after the palletizer was increased. The results showed that as the buffer capacity grew, there was a significant increase in the output of finished products, accompanied by a reduction in palletizer blockages. This trend underscores the importance of buffer capacity as a critical factor for system performance. However, the ideal buffer capacity was found to be 14 pallets, at which point the palletizer operates without blockages. Increasing buffer capacity beyond this would require considerable floor space, which may not be feasible or economically viable in practice.

The final decision on which scenario to implement should consider not only the efficiency gains but also the associated costs and the practical feasibility of its implementation in a manufacturing environment.

5 Proposed Solutions

Standing out for its adaptive approach, which allows products to decide their destination based on estimated processing times and the availability of subsequent machines, it is proposed that the current system be adapted to the one described in Scenario 2. The implementation of this scenario requires some strategic changes and operational adjustments that, although they involve initial investments, offer significant benefits in terms of efficiency and productivity.

The implementation of this proposal involves the following key changes:

- **New Wrapping Machine:** A new wrapping machine will be installed on side 2.
- **Additional Sensors:** New sensors will be installed on the conveyor belts, between rotations and between the second rotation and strapping machine 2. This change will allow products to move continuously to the next machines.
- **Adaptive Programming on the First Rotation:** The system will be programmed so that batches of boxes can make decisions about their destination based on the availability of the following machines.
- **Simultaneous Batch Entry:** The system must also allow for two batches to enter simultaneously in the first rotation, provided they belong to the same order. This measure aims to optimize production flow and reduce processing time for larger orders, avoiding the dispersion of batches across different points in the system.

These changes are expected to improve production efficiency by 10% and reduce palletizer lockout time by 57.7%, enabling more continuous equipment operation. Considering the company's annual turnover of approximately 50 million euros, the projected gains may reach 5 million euros annually.

6 Conclusion

This study at SMSA effectively addressed significant operational challenges by emphasizing bottleneck optimization in the packaging sector. Through systematic analysis and scenario simulations, the project generated actionable recommendations aimed at streamlining workflows, reducing lead times, and enhancing overall production efficiency. The proposed solutions underscored the importance of integrating real-world data into simulation models, fostering a robust, data-driven approach to process improvement.

A structured project management approach supported the planning, task allocation, and monitoring of progress, while digital communication tools enabled effective collaboration among all stakeholders. Managing the dual demands of academic and project work required adaptability and informed decision-making, contributing to the project's success.

The project highlighted the potential benefits of fully integrating the new packaging machine, emphasizing the necessity for timely installation and adaptation of production processes. In the future, the implementation of the proposed improvements and the continued application of scenario simulations will enable SMSA to transition to a more agile, sustainable, and competitive operating model.

Moreover, this case provides a valuable reference for both professionals seeking to optimise similar production systems and engineering educators aiming to incorporate real-world simulation into industry-based PBL initiatives.

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Project-Based Learning in cooperation with Industry: a case study in a textile company

Ana M. Pereira¹, Ana R. Calvão¹, Beatriz Silva¹, Davide Rodrigues¹, Diana Lima¹, Gonçalo Mendes¹, José P. Martins¹, Maria B. Gomes¹, Rui M. Sousa^{1,2}

¹ Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal

² ALGORITMI Centre, School of Engineering, University of Minho, Guimarães, Portugal

Email: [pg56161, pg56162, pg56166, pg56173, pg56174, pg57313, pg57319, pg57323]@alunos.uminho.pt, rms@dps.uminho.pt

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Abstract

In the 1st year, 1st semester, of the master's in Industrial Engineering and Management at the University of Minho, students develop a project in interaction with companies, integrating knowledge of the semester's curricular units, using the Project-Based Learning (PBL) approach. The objective of this paper is to present the project carried out by a team of students at a textile company, aiming to improve the performance of the dyeing and finishing section. The project followed an agile approach, starting with an analysis/diagnosis phase, followed by improvements development and results discussion. Regarding the theoretical background, this paper is based on PBL as an active learning approach and on the Lean Manufacturing paradigm for the technical work developed in the company. Project management encompassed communication, information and time management, and task organization. Various tools were adopted, namely: WhatsApp and Gmail for communication, Microsoft Teams for information management, and ClickUp for time and task organization. Additionally, specific roles were assigned to team members, peer reviews were carried out, and rigorous milestones and deliverables were set. Regarding technical work, the focus was on creating the necessary conditions to allow the effective calculation of the OEE (Overall Equipment Effectiveness) indicator for the section under study, something that did not exist due to the high diversity of products. Subsequently, using Ishikawa diagrams, it was possible to identify/analyse the main reasons for machines stoppages. The intervention work used PDCA (Plan-Do-Check-Act) cycles. The project produced significant outcomes: students gained direct exposure to the business environment and developed competences in project management, communication, and teamwork. Likewise, the company has also benefited from implementing OEE calculation, identifying process improvement opportunities and adopting Lean Manufacturing practices. This case study highlights the advantages of the PBL approach, demonstrating its positive impact on both students' training and the performance of the partner company.

Keywords: Project-Based Learning; Project Management; Overall Equipment Effectiveness; Lean Manufacturing.

1 Introduction

The increasing complexity of industrial processes and the growing demand for efficiency and adaptability in production environments have intensified the need for innovative educational methodologies that bridge the gap between academia and industry. Project-Based Learning (PBL) has emerged as an effective pedagogical approach that fosters experiential learning, equipping students with the technical, managerial, and teamwork competences required in real-world settings. Although PBL has been widely explored in engineering education, its implementation in close collaboration with industry (real production environments), remains underrepresented in the literature. This study contributes to addressing that gap by examining a University-Business Cooperation (UBC) project developed in the textile sector. In this context, this study explores the implementation of a PBL initiative developed in collaboration with a textile company, aiming to address a practical challenge within the organisation's production system.

The primary objective of this project was to integrate students of the master's in Industrial Engineering and Management, at the University of Minho, into an industrial environment where they could apply theoretical

knowledge to a real case study, focusing on both the technical aspects of production management and the overall project execution. A key component of this integration was the development of team management competences, as students were required to collaborate effectively, distribute responsibilities, and make collective decisions to achieve the project objectives. Regarding the project's technical side, the work specifically addressed the challenges related to calculating the Overall Equipment Effectiveness (OEE) of the dyeing and finishing section and proposed solutions to enhance data accuracy and operational effectiveness. By analysing Key Performance Indicators (KPI), identifying inefficiencies, and implementing structured improvements, the project sought to deliver tangible benefits to the company while simultaneously enhancing the students' professional and interpersonal competences.

This paper presents the PBL initiative results, detailing the diagnostic analysis, main challenges encountered, and proposed improvements. Furthermore, it discusses the implications of integrating students into industrial problem-solving and evaluates the effectiveness of PBL as a methodology for bridging academic knowledge with industry needs. Particular attention is given to the role of team management in facilitating collaboration, enhancing problem-solving capabilities, and fostering leadership competences among participants.

2 Theoretical Background

2.1 Project-Based Learning

Problem-Based Learning (PBL) is a teaching method focused on students' active engagement through the resolution of complex, real-life problems. This approach encourages exploration of various pathways to arrive at valid solutions, fostering meaningful learning by stimulating critical thinking, collaboration, and independent knowledge acquisition (Moustafa, & Al-Rashida, 2024). At its core, PBL is defined by its interactive and interdisciplinary aspects. It involves structured projects where students work together to propose solutions to real-world challenges, enhancing teamwork and active engagement, and aligning with both academic and professional objectives (Tijo-López & Mejía-Aguilar, 2024). The University of Minho (UM) has adopted the PBL approach since the academic year 2004/2005, particularly within the Industrial Engineering and Management program, with several studies highlighting its implementation and positive impact over the years (Alves et al., 2020, 2021; Fernandes et al., 2021; Lima et al., 2017, 2018; Sousa et al., 2023).

Additionally, PBL emphasizes a balance between theoretical knowledge and practical application, allowing students to improve their problem-solving and communication abilities through collaborative workshops and activities; these experiences are essential for their future careers. One significant advantage of PBL is its contribution to developing both practical and social competences. When academic hackathons are integrated into PBL, engineering students, for instance, gain competences in social entrepreneurship, fostering innovation and creating social impact by addressing real-world problems (d'Escoffier & Rezende, 2024).

Moreover, PBL also plays a key role in enhancing emotional resilience and coping mechanisms. Through participatory activities, students are able to face emotional challenges within group settings, promoting personal and professional growth. It also cultivates skills such as empathy, adaptability, and conflict resolution (Martínez & Varela, 2024). PBL stands as a transformative educational approach, empowering students with real-world problem-solving abilities and structured project planning. It prepares them for both professional success and positive societal impact, while simultaneously fostering technical, social, and emotional competencies essential for navigating a constantly changing world.

2.2 Lean Manufacturing

Lean Manufacturing is a management and production philosophy aimed at maximizing customer value through the systematic elimination of waste (Muda) and continuous improvement (Kaizen) of production processes. This approach has its roots in the Toyota Production System (TPS), developed by Taiichi Ohno at Toyota in the post-World War II period, and was later consolidated and adapted for other sectors by various scholars and professionals (Ohno, 1988; Shingo, 1989; Liker, 2005). Developed by Taiichi Ohno in response to the limitations of the Fordist model, the TPS identified seven types of waste (Muda): overproduction, waiting, transport, overprocessing, inventory, motion, and defects (Ohno, 1988). Additionally, a later contribution identified an eighth type of waste - the underutilization of human potential - emphasizing the importance of engaging employees' skills and knowledge (Liker, 2005). The TPS also introduced the concepts of Just-In-Time (JIT) and Jidoka (automation with a human touch) to ensure demand-driven production and built-in quality at every stage (Ohno, 1988). The concept of Lean gained global recognition with the work of James Womack, Daniel Jones, and Daniel Roos, who in their book *The Machine That Changed the World*, analysed the TPS and demonstrated how it was significantly more efficient than traditional mass production models (Womack, Jones & Roos, 1990). Subsequently, in 1996, Womack and Jones systematized Lean thinking into five fundamental principles in the book *Lean Thinking: Banish Waste and Create Wealth in Your Corporation* (Womack & Jones, 1996). Those five core principles of Lean are: defining value, mapping the value stream, creating continuous flow, establishing pull-based production, and pursuing perfection through continuous improvement (Kaizen).

Lean Manufacturing is founded on the principle that value is defined solely by the customer, and thus, all activities that do not directly contribute to value creation should be eliminated. Unlike traditional mass production - characterized by waste, namely excess inventory among others, and limited responsiveness - Lean aims to establish a continuous production flow, delivering the right number of products at the right time, in the right quantity (i.e. JIT), and with minimal waste (Ohno, 1988). In fact, Womack, Jones, and Roos (1990), demonstrated that TPS outperformed traditional models in efficiency, quality, and cost. Their research also emphasized the importance of a culture oriented toward continuous improvement and employee engagement.

Although initially developed for the automotive industry, Lean principles have subsequently been adapted across various sectors such as healthcare, services, and logistics, leading to reduced lead times, enhanced flexibility, lower operational costs, and improved product and service quality. However, successful Lean implementation requires a deep cultural and operational shift, emphasizing continuous waste elimination and active employee participation.

3 Project Development

3.1 Project Management

Upon the presentation of the project's problem statement to the team, it became imperative to identify tools capable of planning and monitoring the project to ensure optimal organisation and the attainment of desired outcomes. The team adopted the Project Model Canvas (PM Canvas), a simplified visual tool for collaborative project planning, which revolves around essential questions such as "Why?", "What?", "Who?", "How?", "When?" and "How much?" (Project Model Canvas Background, n.d.). This tool was pivotal in the visual and direct identification of problems and opportunities that underpin the project. PM Canvas facilitated a detailed definition of the project's deliverables and their integration, while also identifying risks and constraints that could potentially hinder the project's success. It provided a clear timeline for each major task. Moreover, PM Canvas addressed human and financial factors crucial for the project's success, including the team, stakeholders, and costs (Figure 1).

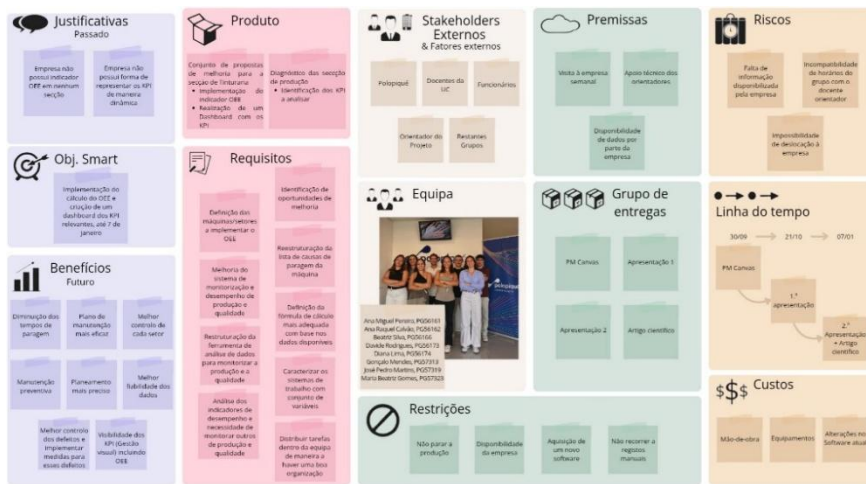


Figure 1. PM Canvas

Efficient communication was a cornerstone of the project's success, particularly in the interaction with the company. Weekly face-to-face meetings at the company were critical to ensuring a clear and direct exchange of information, fostering an in-depth understanding of the project's needs and objectives. Supplementary communication channels such as telephone and email maintained a consistent flow of information, even remotely. For day-to-day interactions, tools such as WhatsApp and Microsoft Teams enabled prompt and immediate responses, facilitating the resolution of urgent issues and promoting agile collaboration.

Microsoft Teams was utilised as the primary communication channel and as a central repository for file sharing and documentation, including meeting minutes, progress reports, and other essential project records. The categorisation of documents enabled swift information retrieval, minimised redundancy, and ensured alignment across all project components. Files were periodically updated not only by team members but also by the company supervisor, which contributed to keeping documentation current and accessible to all stakeholders. This structured and collaborative approach to documentation facilitated coordination and promoted a more efficient workflow. In parallel, the ClickUp platform was specifically adopted for task management, priority setting, and monitoring individual and collective progress. One of the key advantages of ClickUp was its availability as a mobile application, which enabled team members to receive real-time notifications and reminders. This feature proved particularly beneficial in alerting users to approaching deadlines, thereby enhancing time management and responsiveness. These tools were employed in a complementary manner, ensuring functional centralisation of information: Microsoft Teams centralised communication and documentation, while ClickUp structured the team's operational and practical work. The use of these platforms not only centralised relevant information but also served as organised repositories for tracking progress and sharing regular updates, ensuring all participants remained informed and synchronised. Communication with academic supervisors, particularly the project advisor, was strategically important. Regular updates via Microsoft Teams provided a clear and structured view of task progression, while telephone and email contacts ensured swift and effective support whenever necessary. This combined approach strengthened connections between stakeholders and ensured transparent and efficient expectation management.

Following the establishment of planning and communication methods, the team moved on to project monitoring. Microsoft Project (MS Project), a software tool focused on project management, was utilised for its capabilities in scheduling, resource allocation, progress monitoring, and generating useful control reports, namely the burndown chart represented in Figure 2.

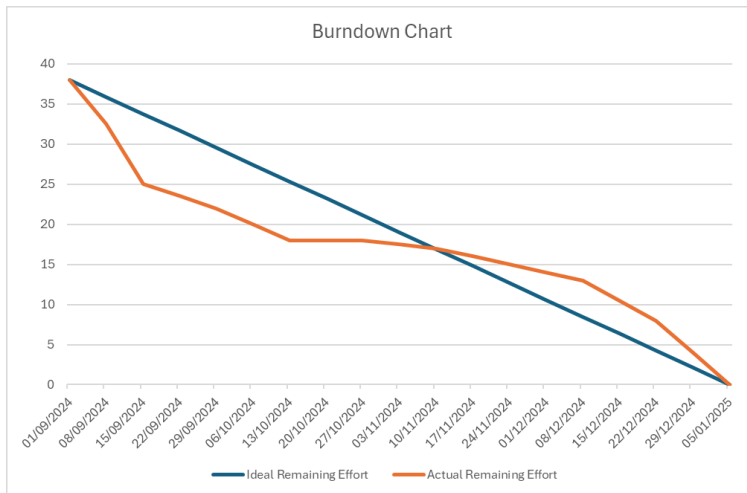


Figure 2. Burndown chart

The burndown chart was essential for monitoring the actual progress of the project (number of tasks remaining) in relation to the idealised progress.

3.2 Work at the Company

The company under study operates in the textile sector, specialising in the production of knitted fabrics and products made from both natural and synthetic fibres. The primary objective of this PBL semester was to combine the academic development of students' technical competences with the resolution of a real-world industrial problem, fostering practical collaboration between university and industry (Lima et al., 2017).

During the initial phase, students conducted an in-depth diagnostic assessment of the company's production line, focusing on some KPI. Particular emphasis was placed on the calculation of Overall Equipment Effectiveness (OEE) of the dyeing and finishing section, which assess equipment performance based on three dimensions: availability, performance, and quality. Several challenges were identified that hindered the accurate calculation of OEE. The company relied on manual records, leading to gaps and inconsistencies in information, particularly regarding standard cycle times, downtime and actual production. Unplanned stoppages were not adequately identified or classified, making it difficult to analyse production losses. Additionally, the monitoring system was rudimentary, lacking digital tools to integrate real-time production data. Another challenge was the limited understanding of the OEE concept among employees, which affected engagement and commitment to improvement initiatives.

Based on this diagnosis, the group proposed feasible and context appropriate solutions, aimed at enhancing operational efficiency and establishing a robust foundation for KPI monitoring. One key recommendation was the automation of data collection, specifically cycle times and stoppages, through the integration of simple hardware into machinery. The adoption of cost-effective software was also suggested to centralise and visualise real time data. In this context, Power BI was employed as the primary data visualisation tool. It enabled the creation of interactive and user-friendly dashboards, thereby enhancing the accessibility and interpretation of performance metrics across different organisational levels. Figure 3 illustrates the dashboard developed for OEE monitoring.



Figure 3. Dashboard for OEE monitoring

In general terms, to support systematic performance tracking, KPI reporting mechanisms were designed and implemented. Weekly and monthly report templates were created for OEE monitoring, incorporating visual tools such as trend charts and loss analysis graphs. Realistic performance improvement targets were defined using historical company data and relevant industry benchmarks.

Standardisation and operational training were also central to the proposed interventions. A structured guide was developed to categorise production losses according to the OEE model, and targeted training sessions were delivered to both machine operators and production managers to ensure consistency in data collection and interpretation practices.

In addition, measures were introduced to foster a culture of continuous improvement involving Plan-Do-Check-Act (PDCA) cycles. Employees were encouraged to contribute to the identification of root causes of inefficiencies, using Ishikawa Diagrams, and to propose process enhancements. Cross functional communication was also promoted, especially among maintenance, production, and quality departments, to support coordinated and effective corrective actions.

4 Discussion of Results

The project successfully demonstrated the effectiveness of Project-Based Learning (PBL) in bridging academic training with real-world industrial challenges. The structured methodologies employed enabled the team to achieve measurable outcomes in both project management and technical implementation in the company while navigating practical constraints.

The Project Model Canvas (PM Canvas) proved instrumental in establishing a clear project framework from the outset, effectively mapping objectives, deliverables, and associated risks (Ferreira et al., 2020). This visual planning tool facilitated team alignment and maintained focus throughout the project. Complementing this approach, the burndown chart (Figure 2) served as a dynamic monitoring mechanism (Vajda, 2009), allowing the team to track the project's progress. These practices were particularly valuable given the tight academic semester timeframe, allowing the team to balance depth of analysis with timely deliverables.

The core technical achievement involved establishing the foundations for Overall Equipment Effectiveness (OEE) calculation in the dyeing and finishing section. The team developed a product categorization system based on standard cycle times (25 categories), significantly improving the accuracy of equipment efficiency analysis. A notable accomplishment was the development of a Power BI dashboard for performance monitoring

(Figure 3). However, designing an interface that accommodated the diverse informational needs of operators, supervisors, and management tiers presented unexpected challenges, revealing organizational differences in data literacy and usage patterns. It is important to note that prior to this project, the company did not have a procedure for calculating OEE, due to its production environment complexity. As such, this initiative aimed to design and implement the fundamental conditions for monitoring OEE, so it is not (yet) possible to compare before and after values of this KPI. Nonetheless, the work laid the groundwork for future performance tracking and continuous improvement initiatives.

Through root cause analysis using Ishikawa diagrams, the team was able to identify predominant sources of unplanned downtime (setups, worker/shift change, and machine breakdowns), while PDCA cycles enabled structured solution analysis (Taufik, 2020). The team standardized manual data collection procedures to minimize inconsistencies and proposed a plan for future automation of the OEE calculation.

Several operational challenges emerged during implementation, including incomplete production data requiring validation, varying digital literacy levels among personnel, and compressed timelines for solution refinement. These were addressed through feedback meetings with company representatives. The experience highlighted both the potential and limitations of applying academic methodologies in industrial settings, particularly regarding data quality and organizational readiness for change.

This PBL initiative not only delivered actionable improvements for the partner company but also provided students with transformative learning in translating classroom knowledge to industrial practice. As highlighted by Lima et al., (2017) and Fernandes et al. (2014), long-term application of project-based methodologies in engineering education fosters the development of transversal competencies such as teamwork, communication, and problem-solving. Although the project was carried out in a team setting, it is possible to identify individual learning outcomes through the students' grades in the curricular units that supported the project (Project Supporting Courses - PSC) and in the project itself, which reflected each student's capacity to apply technical concepts and tools. On the other hand, transversal competences were mainly evaluated at the team level, through presentations, reports, and project follow-ups. The project highlighted how structured academic frameworks can successfully interface with the dynamic requirements of manufacturing environments when supported by responsive project management and technical adaptability, an approach aligned with the findings of (Alves et al., 2023), who emphasize the importance of university-business cooperation and adaptive pedagogy in enhancing student preparedness for real-world challenges.

Despite the project's achievements, certain limitations must be recognised. Firstly, the lack of a procedure for calculating OEE, as well as for collecting the necessary data in a structured way, has prevented specific improvements from being made in this area. Secondly, the solutions developed were highly tailored to the operational context of a single textile company, which limits their external validity. Moreover, the lack of long-term follow-up prevented the evaluation of the sustainability and broader impact of the implemented changes.

5 Conclusion

The objectives defined at the outset of this study were successfully achieved, as the Project-Based Learning (PBL) initiative enabled students to engage with a real-world industrial challenge while delivering meaningful insights to the partner company. The analysis of the production system, particularly the limitations associated with the calculation of Overall Equipment Effectiveness (OEE), led to a structured diagnostic process that informed the development of feasible improvement strategies. These included proposals for the digitalisation of data collection and the improved categorisation of production losses, both aimed at establishing a more effective performance monitoring framework.

Throughout the project, several key factors contributed to its successful execution. The use of structured project management tools, such as PM Canvas and ClickUp, played a central role in prioritising tasks and ensuring adherence to timelines. The flexibility of the approach adopted allowed strategies to be adapted continuously in response to evolving circumstances, maintaining alignment with both academic requirements and industrial expectations. Furthermore, the active involvement of stakeholders through regular meetings with company representatives helped to align goals and reduce the effects of unexpected delays. The ability to work with partial or evolving information proved to be an essential skill for managing uncertainty in such dynamic environments.

Despite these strengths, the project encountered several challenges. In the early stages, inconsistencies in manually recorded data hindered the establishment of reliable baseline metrics. In addition, coordinating the timelines and expectations of academic and industrial partners presented logistical difficulties. These issues highlighted the importance of strong internal organisation, effective communication, and the ability to plan flexibly. Addressing these aspects may lead to more efficient execution of future collaborative projects.

A significant outcome of the initiative was the development of both technical and transversal competences. Alongside the application of engineering knowledge, students strengthened their skills in areas such as communication, teamwork, problem-solving, and time management. The experience also emphasised the value of team structure, leadership, and accountability, especially when operating under real industrial constraints.

Looking forward, future efforts should focus on implementing the proposed solutions on a wider scale, including the integration of automated data collection systems and the refinement of OEE monitoring methodologies. Further research could examine the long-term impact of these measures on production efficiency and assess their adaptability across similar industrial contexts. In parallel, continued enhancement of the PBL framework, with particular attention to stakeholder interaction, feedback processes, and collaborative decision-making, could improve the effectiveness of academic and industrial partnerships and further strengthen student preparation for complex professional environments.

By documenting the application of PBL in close collaboration with an industrial partner, this study offers a concrete example of how academic learning can be effectively aligned with real-world practice. It contributes to the limited body of literature on University-Business Cooperation (UBC) within PBL contexts, especially in high-variability production environments. Future research could explore the long-term impact of such initiatives and assess their scalability across different industrial sectors.

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Engagement and Representation in STEM: Active Learning from the Perspective of Undergraduate Extension Students

Anne Karoline G. de Oliveira¹, Luísa Gabriela Ferro da Frota¹, Andressa Fonseca Coelho¹, Kelly Cristina M. Teixeira¹, Geovana Siqueira Gomes¹, Laura Beatriz L. de Sousa¹, Maura Angelica Milfont Shzu¹, Dianne Magalhães Viana¹

¹ University of Brasília, Brazil

Email: anne.oliveira@aluno.unb.br, luisaferro9@gmail.com, andressa.afcc@gmail.com, kelly.cmteixeira98@gmail.com, geovana.gomes@aluno.unb.br, laurabeatrizsousa2@gmail.com, maura@unb.br, diannemv@unb.br

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Abstract

Gender inequality in the exact sciences and engineering remains a global challenge. The *Meninas Velozes* Program seeks to address this issue through active learning methods and strategies, encouraging girls' participation in Science, Technology, Engineering and Mathematics (STEM) within an integrated STEAM approach. The inclusion of the Arts ("A" in STEAM) promotes creativity, critical thinking and interdisciplinary connections, reinforcing the relevance of these fields to students' lived experiences and broadening the appeal of science and technology learning. This study analyzes the impact of the pedagogical workshops developed by the Program, incorporating the perspectives of undergraduate students and the results of assessments applied to elementary school girls from public schools in Brasília, Brazil. The methodology is based on action research and includes active learning strategies such as flipped classrooms, problem-based learning and gamification. The workshops were structured into three categories: (i) integration and motivation; (ii) STEM/STEAM activities; and (iii) study organization and project presentation. Undergraduate students acted as tutors, promoting a collaborative environment and encouraging active participation. The results indicate that the workshops increased the students' interest in STEM and strengthened their self-confidence and sense of belonging. The undergraduate tutors emphasized that the intersectional and contextualized approach helps to reduce structural barriers by integrating academic content with students' social and cultural realities. Their presence as facilitators further increased female representation in these fields, promoting a cycle of inspiration and support. It is concluded that active learning approaches, combined with representation and ongoing support, are essential for girls' engagement in STEM. The results reinforce the need for educational policies that promote and expand similar initiatives.

Keywords: STEAM, STEM, active learning, gender equity

1 Introduction

Since childhood, individuals belonging to a society go through a process of acculturation, where their behavior and personality are mostly conditioned according to the characteristics considered normal for their biological sex. In the Brazilian context, the socialization of girls is in line with what Bell Hooks says in "Feminism Is for Everybody: Passionate Politics" they are given a role of subordination, being taught to be docile, attentive and to avoid confrontation (Hooks, 2018, p. 35), and there is also a notion that personal value is linked to their physical appearance and how useful they are to others. These constraints have a profound impact on girls' and women's choices regarding the careers they consider possible to enter, an effect that intensifies when we talk about public elementary school students, such as the participants in the *Meninas Velozes* Program in the city of Santa Maria - DF, which has, according to data provided by the Federal District Planning Company, a worrying Multidimensional Poverty Index (Gonçalves, 2015). In addition to financial vulnerability, there are other barriers that are invisible to the naked eye, but which are well known and prevent them from seeing themselves facing the common challenges of STEM (Science, Technology, Engineering and Mathematics) careers. We're talking about low self-esteem, self-sabotage and a lack of representation and encouragement within the community to which they belong. It can be seen that even after all the movement to promote women in higher education, we see a disparity in the number of men and women in STEM areas, with a total of 34% female participation in Brazil (Nascimento et al., 2023, p. 5), something far from the minimum parity threshold of 45% established by UNESCO (2017).

In this context, the *Meninas Velozes* Program stands out for promoting workshops with active learning strategies aimed at elementary school students in the Federal District, relying on the direct work of tutors from different areas of knowledge, such as Mechanical Engineering, Forestry Engineering, Chemical Engineering, Production Engineering, Anthropology, Pedagogy, Social Sciences and Communication. These tutors lead the teaching process, and are also primarily responsible for designing, mediating, and carrying out the activities. These responsibilities drive the development of essential skills in undergraduates, such as autonomy, communication, teamwork, leadership, and the ability to plan and coordinate educational activities. In addition to the aspects mentioned above, little is known about how the tutors themselves perceive the impact of active learning on the trajectory of the participants, especially in relation to awakening interests in STEM areas. The aim of this work is to understand how the tutors of the *Meninas Velozes* Program perceive the impact of their actions in developing workshops using active learning to promote STEM areas among elementary school students in the Federal District.

1.1 Overview of the Meninas Velozes Program

The *Meninas Velozes* Program is an initiative of the Faculty of Technology, in partnership with the Faculty of Education and the Faculty of Science and Technology in Engineering, of the University of Brasília (UnB), to help reduce gender inequality in the areas of Science, Technology, Engineering and Mathematics (STEM), promoting female protagonism from primary to higher education. Composed of two research projects and four extension projects, the program involves actions based on pedagogical workshops, mentoring, events, and interactive activities. These initiatives aim to awaken girls' and women's interest in STEM areas and deconstruct gender stereotypes while encouraging the development of socio-emotional skills and promoting a more inclusive academic and professional environment.

The STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach used in the projects proposes an integrated and interdisciplinary way of teaching and learning by uniting these areas, with a focus on developing critical thinking, creativity, and collaborative problem-solving. It emerges as an inclusive alternative, integrating creativity, critical thinking, and interdisciplinarity to make science and technology more accessible to girls (Salehjee & Watts, 2023). The STEAM approach allows girls from different backgrounds to develop essential 21st century skills such as communication, innovation, collaboration, and problem-solving (Liao, Motter, & Patton, 2016, p. 29). This methodology also enables the re-signification of past experiences, strengthens present realities, and creates new future possibilities (Toliver, 2021, p. 133), thus contributing to a transdisciplinary education (Colucci-Gray, 2022). In the *Meninas Velozes* Program, this approach is applied within the workshops through tools such as the flipped classroom, hands-on activities, gamification of assessments, One-minute-paper and Think-Pair Share. These tools encourage the creation of creative solutions, such as the construction of prototypes, scientific experiments, and collective projects.

1.2 Active Learning in the context of Meninas Velozes Program

The banking education system is characterized by rigidity between the roles of teachers and students. The educator holds the knowledge and transmits the information unilaterally. The students are therefore vessels into which this content is passively poured, given their supposed lack of knowledge. A hierarchical silence is therefore maintained, centered on the quantitative transmission of information, with no sensitivity related to how this content is passed on (Freire, 1987). On the other hand, liberating or problematizing education understands students as subjects in their learning process, thus encouraging them to develop an autonomous way of understanding the world around them (Ferreira Paiva et al., 2017).

Thus, the student takes an active stance in challenging situations in which critical thinking, creativity, empowerment, and communication skills are valued and encouraged, while being fundamental to academic and civic development (Liao, Motter, & Patton, 2016; Salehjee & Watts, 2023). Thus, the active learning strategies applied by the *Meninas Velozes* undergraduate students focus on practicing liberating education and reinforcing the knowledge acquired by giving students autonomy and promoting meaningful learning (Tavares, 2010).

Workshops: In this pedagogical context, the “workshop” refers to a collective teaching and learning strategy, using everyday elements of the students throughout their learning process, with the aim of critically connecting theory and practice, stimulating active and collaborative student participation, developing critical and reflective thinking through the action-reflection-action cycle, and strengthening student autonomy and protagonism (Fornazari, & Obara, 2017). In the project, the “workshops” are group meetings between tutors, elementary school students, and teachers in which active learning activities take place.

In-class exercise: The in-class exercise is an applied strategy in which tutors suggest a question or challenge to students. In this case, groups of two to four students are formed, with one in each group responsible for taking notes during the discussion (Tasaka, & Neto, 2013). At the end of the lesson, the work is brought together for a collective debate that consolidates the content by exchanging ideas, correcting mistakes in real time and deepening learning. The practice encourages collaboration, logical reasoning and contextualized problem solving.

Flipped classroom: Another strategy commonly applied by the project is the Flipped Classroom, in which the content is previously presented to students via the internet. Tutors then provide students with support material (such as texts, activities, and recorded or selected videos), with the aim of developing a complementary activity in the classroom, either individually or collectively (Moreira, 2018). Thus, students are led to a “reflective doing”, which consists of practice followed by reflection on it, encouraging autonomy and initiative in their learning process, as well as promoting greater interaction between students, tutors and teachers (Moreira, 2018).

Think-Pair-Share: Another collaborative strategy used by the project and often mentioned in studies dealing with group teaching in the classroom. It is based on three pillars: time for reflection, time to talk with a colleague, and time to share with a larger group (dos Reis & Barreto, 2017). The strategy encourages critical thinking and collaboration by involving moments of individual reflection and group sharing, favoring engagement and the collective construction of knowledge.

Gamification: One of the strategies most used by the project is playful devices to engage and motivate students (Soprani, de Abreu Mól, & do Espírito Santo, 2025). Therefore, it consists of applying elements and dynamics that arouse students' interest, such as challenges and rewards, in order to instigate them to actively participate in their learning process by promoting engagement, creativity, and problem-solving. Within the project, gamification takes place mainly through the application of Quizzes, which are question-and-answer games, with the aim of consolidating the content immediately after the tutor's presentation.

One-minute-paper: A simple formative feedback technique applied during or after classroom activities. It summarizes students' perceptions of certain subjects and can describe something like “what I learned today” or “what I still don't understand.” This brief written reflection allows the student to mentally summarize the content and express doubts. It can encourage immediate revision of the content and provides tutors with information on the effectiveness of the lesson (Domokos & Huey, 2023).

Practical activities: These are based on learning from experience (Holstermann, Grube, and Bögeholz, 2010). This strategy strengthens students' connection with the content by contextualizing and individualizing learning, promoting retention, critical thinking, problem-solving, and active engagement, making knowledge more concrete and meaningful (Fornazari & Obara, 2017). In the project, these are the final activities of the workshop, after the student's exposure to the proposed topic. As such, the activity varies according to the topic, whether it's assembling electrical circuits, modeling systems for 3D printing, or making notebooks after a bookbinding lesson, for example.

1.3 Tutors as facilitators of knowledge construction in active learning contexts

Changing the learning process to a gender-sensitive STEAM approach requires a reframing of the roles of teachers and mediators. Instead of limiting themselves to the linear transmission of knowledge, these professionals become facilitators of the educational process, promoting new power relations and dynamics of engagement, breaking down traditional and inflexible structures (Pearson, & Somekh, 2006, p. 537). Thus, the teacher's role goes beyond giving instructions to rather create a dynamic environment where students take on leading roles in the construction of knowledge.

From the planning to the execution of activities, mediators play a strategic role in choosing authentic contexts and integrating innovative methodologies that favor the active participation of students (Bacich & Holanda, 2020). The mastery of different pedagogical practices and digital resources enhances this educational intention, ensuring a meaningful learning process connected to the realities and interests of students (Allen-Handy et al., 2020; Bacich & Holanda, 2020; Salehjee & Watts, 2023). Therefore, the mediating role of the educator becomes central in implementing effective teaching strategies, adapting processes according to students' needs, and strengthening students' autonomy (Pearson & Somekh, 2006; Bacich & Holanda, 2020).

While aiming for a gender-sensitive education, it is essential to create safe spaces that do not impose barriers to the growth and performance of STEM girls. In the *Meninas Velozes* Program, undergraduate tutors play an inspiring role by sharing their academic trajectories, cultural, and personal experiences. The interdisciplinary composition of the Program, which brings together fields from the humanities and engineering, enriches the training process, favoring the exchange of knowledge. This approach fosters identification between students, strengthens bonds, and significantly expands the possibilities for engagement with the sciences. The project thus contributes to building a more inclusive and diverse future for STEM subjects.

2 Research Design

This study adopted a qualitative approach based on critical educational action research, seeking not only to understand but also to continuously improve the pedagogical practices developed within the framework of the *Meninas Velozes* Program. Critical educational action research, in this context, was conceived as a cyclical and collaborative process in which the subjects involved, in this case the undergraduate tutors themselves, actively participated in the construction of knowledge, the identification of problems, and the proposal of improvements to the strategies used in the educational workshops (Koerich, 2009). The methodology combined three main fronts: (i) a narrative literature review, which provided the theoretical basis for the main guiding concepts of the Program, such as active learning, female participation in STEM areas, and inclusive pedagogical practices; (ii) the application of a digital questionnaire, constructed and analyzed jointly by the tutors; and (iii) a collaborative reflection with structured feedback, which is based on the agile *Start, Stop, Continue* methodology, aimed at critical evaluation and improvement of the pedagogical actions developed

2.1 Data Collection

A collaborative reflection session was held with the project monitors, with the aim of collectively reflecting on the pedagogical practices adopted, the effectiveness of the actions, and possible methodological improvements. The discussion made it possible to identify common perceptions, difficulties faced, and suggestions for improving the workshops. This qualitative discussion made it possible to identify patterns of perception, challenges faced, and proposals for improving workshops. The main data collection tool consisted of this guided reflection, combined with the results obtained through a digital questionnaire. The questionnaire was drawn up collectively by the undergraduate monitors, based on the demands observed during the project and anchored in the theoretical references that guide their practice. The purpose of this instrument was to promote a formative and reflective process among the participants.

The agile *Start, Stop, Continue* methodology guided this reflection, allowing tutors to identify practices that should be maintained, reformulated, or abandoned. This approach encouraged the development of analytical and self-reflective skills, as well as reinforcing the participatory nature of the research. This reflective process enriched the interpretation of the data and served as a space for continuing education for the participants, promoting alignment between theory and practice. The discussions raised strong points and aspects to be improved in the methodologies applied, contributing to the continuous improvement of the Program, leading to a formative, participatory, and transformative investigation in which the tutors in the research are both agents and analysts of their own pedagogical practice.

To systematize the pedagogical purposes guiding the process of collaborative reflection with the program's tutors, Table 1 below shows the main objectives of the activities carried out. The organization of the objectives seeks to highlight the methodological proposal of the *Meninas Velozes* Program and the formative, reflective, and investigative goals that guided the research.

Table 1. Active Learning Strategies' goals

Active Learning	Objective
Practical activities (hands-on)	Motivation, integration of theory and practice, autonomy, self-confidence to build new things.
One minute paper (new technique)	Reflection on theory/practice, survey of successes/mistakes, improvement of workshops.
Gamefication	Fun, additional motivation, incentive and participation (boost engagement).
Classroom exercises (Quizzes + Questions)	Engagement in the classroom.
Flipped classroom	Prior preparation, time optimization, connection with the topic, and autonomy.
Think-Pair-Share	Interaction, collective construction, exchange of knowledge, dialog / self-exposure, courage.

3 Results

Table 2 was drawn up from the discussion among the five tutors. In it, it was possible to identify perceptions about the application of active learning strategies and whether they effectively engage students in STEM. We also analyzed the effectiveness of the practices and tried to assess what should be improved, continued, or discontinued. They also came up with ideas for practices that could be implemented. This meeting proved to be an organizational opportunity for the Program and a fruitful alignment between the monitors. In addition, considering the integrative nature of the workshops, the techniques are applied together, which directs the analysis to a macro view in such a way that the development of one technique affects the development of others. Based on this reflection, the activities carried out in the project were evaluated, a summary of which can be seen in the table below.

Table 2. Active Learning Strategies - Structured Feedback through *Start, Stop and Continue*

Active Learning	Start	Stop	Continue
Flipped classroom	Recall topics from the flipped classroom before the presentation / Test playful elements (songs, movies, series)	Assume that basic concepts have already been understood in advance of the lesson / Send the lesson at short notice	Rewarding access to the flipped classroom / Bringing in interesting stories and aspects
Classroom exercises (Quizzes + Questions)	Adding anti-stress meditation breaks / Promoting integration at the start of the workshops with students and monitors, seeking out their experiences	Applying replication exercises, without time for reflection	Add more questions to the reflection and interaction workshop / Bring the questions closer to the girls' reality
Gamefication	Integrate activities more and promote greater student participation / value them at the end of the year	Broadening collective participation	Integrate other methodologies with gamification / Continue with rewards
Practical activities (hands-on)	Structure workshops to allow time for discovery / train monitors to replicate workshops	Promotion of execution workshops, without reflection on the process	Increase the explanation of why and the importance of the content / bring in more activities that generate some physical souvenir product
Think-Pair-Share	Separate the groups to avoid segregation and better integrate the students	-	Do more group activities for exchanges, dialogues and gamification activities
One minute paper (new technique)	Meetings to reflect on the workshops between monitors (once a month) and with students (twice a year)	-	Open up more spaces for feedback (from students and monitors)

3.1 Discussion of Results – Collaborative Reflection with Structured Feedback: Start, Stop, Continue.

The flipped classroom approach is implemented with the aim of preparing students for the activities to be developed in class and optimizing the time available with them. Thus, the class proceeds under the assumption that all students have understood the basic concepts presented in the preparatory material. However, this is not always fully achieved and can sometimes result in reduced fluidity during the lesson. Consequently, the importance of reviewing the key concepts at the beginning of class was emphasized, in order to ensure a common level of understanding among students. Furthermore, the incorporation of engaging content such as music and films was highlighted by the tutors as a strategy that can motivate students to engage with the suggested material in the flipped classroom format, and it is of interest to the tutors to implement this approach. Another practice to be further developed is the timely preparation and distribution of the flipped classroom reference materials, so that students have more time to study the content in advance. Regarding the practices that have been successfully implemented, the tutors noted the value of integrating historical and interesting facts into the presentation, as well as incorporating gamification elements into the flipped classroom. An example of this includes rewarding students who completed the preparatory work at home.

Regarding the in-class exercises, similar issues and solutions were identified as those observed in the hands-on activities. In this case, in addition to the importance of connecting the students' realities to the content being studied and organizing the session time to foster autonomous reflection, the discussion also highlighted the importance of incorporating breaks during the activities. It was thus collectively concluded that it would be valuable to include moments of interaction between the students and the tutors at the beginning of the sessions, not only to strengthen group integration but also to promote moments of relaxation and lightness, which are essential in the context of a fast-paced, productivity-driven society in which these students are immersed.

Gamification, on the other hand, refers to an element present in the workshops, and is developed at specific moments through quizzes, for example. In this case, the importance of integrating the activities into the students' context outside the classroom was identified, in order to enhance the value of participation and engagement. One idea raised during a discussion among the monitors was to award prizes at the end-of-year event that value the students' engagement on social networks, for example. At the same time, in gamification dynamics, individual participation is currently more valued. In this context, the monitors pointed out the importance of promoting gamification dynamics that are also collective, to better integrate the students with each other.

Regarding the hands-on activities, the importance of giving the students more time to make their own discoveries was highlighted, as well as allowing them to reflect on and resolve errors in carrying out the proposed activities, rather than directly reproducing the instructions. At the same time, explaining the connection between the content and its real-life applications was collectively identified as something effective for the students' learning. In addition, another motivating factor is the construction, during the workshops, of artifacts that can be kept by the students, which was pointed out as a positive practice in promoting the engagement of these students. On the other hand, it was observed that making these artifacts generates empowerment due to the accomplishment of an unprecedented task.

Regarding Think-Pair-Share, we identified the importance of this dynamic for the socialization and integration of the students, to engage them collectively in the proposed activity. However, the groups are defined by the students themselves, which limits integration between students who are not friends outside the project. The monitors therefore pointed out the importance of starting to intervene in this group formation, to promote greater integration between all the students.

The One Minute Paper technique was implemented recently and has already shown promise. In this case, feedback was encouraged to be given manually after the hands-on stage. Thus, the promotion of a feedback space for the students resulted in opinions guiding the project, indicating what was positively or negatively received by the students. This result led to a consensus among the monitors on the importance of holding periodic reflective meetings in the project to internally evaluate the activities carried out and better integrate

the monitors and students in the project. As well as bringing about a self-reflection of the students' learning from the activities carried out.

To shed more light on the benefits of the methodologies, the following are testimonies from elementary school pupils that explain the positive impact and self-perception of the active learning strategies used in the workshops. Regarding the robotics and programming workshop, the following feedback was obtained: "I felt very happy, a new experience for me. I'm very interested in programming, and I had fun trying to write the code." , "I feel smart for having managed to assemble the protoboard; it wasn't as difficult as it seemed at first; it was really nice." , "I felt good, happy and excited to be able to understand something I never thought I would." and "I felt proud of myself and also of the colleague who did it with me." In addition, the following is a comment made by another student at the same workshop:

At first I felt helpless and lacked basic knowledge, but after the protoboard started working I was very happy and understood that help is sometimes needed. I did it with my friend, and group (or pair) work is important and sometimes fun. In short, I felt like a DIVA! (Primary school student)

4 Conclusion

Gender inequality in STEM fields is still a global challenge, and this study aimed to understand how the tutors of the *Meninas Velozes* Program perceive the impact of their actions in developing workshops using active methodologies to promote STEM fields among elementary school students in the Federal District. The analysis provided greater clarity regarding the practical application of active learning methodologies, contributing to the improvement of pedagogical planning and fostering a qualified debate on the importance of representativeness and intentionality in educational actions aimed at gender equity in STEM.

The study showed that the active learning approaches, as flipped classroom, classroom exercises, gamification, practical activities, peer learning, and one-minute paper, are methods with great potential for improving teaching and learning when applied to the students' reality. The tutors also made significant gains in terms of the students' engagement, empowerment, and autonomy in their own training process by acting as mediators and facilitators of knowledge.

The agile methodology of Start, Stop, Continue allows us to observe the active learning methodologies that are most effective for the Program, as well as reinforcing the participatory and investigative nature of the project. A key point that emerged was the importance of intentionality in active learning, and also in the choice of physical and symbolic spaces in which learning takes place. Welcoming, interactive, and safe spaces contribute decisively to building bonds and promoting female protagonism in the workshops.

The students' spontaneous reports show their self-perception and confidence, showing that when they feel capable of carrying out new tasks, they recognize themselves as the protagonists of their own learning process. In this way, it can be concluded that active learning, when applied with pedagogical intent, sensitivity and listening, becomes powerful tools for building a more innovative education.

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Use of AI for Risk Response Actions in Undergraduate Final Projects

José C. Pereira¹, Alexandre Sheremetieff¹, Flavio Almeida¹, Fábio Esperança¹, Fabini N. Alvarez¹, Flavio Frade², Francisco Meira²

¹ Master Program in Engineering - UCP (Petropolis Catholic University), Petropolis, Brazil

² Engineering Centre – UCP (Petropolis Catholic University), Petropolis, Brazil

E-mail: josecristiano.pereira@ucp.br; alexandre.sheremetieff@ucp.br; flavio.book@gmail.com; fabiohope@hotmail.com; fabini.alvarez@ucp.br; flavio.frade@ucp.br; francisco.meira@geaerospace.com.

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Abstract

Project-based learning (PBL) has gained prominence in engineering education for its ability to enhance students' professional knowledge through practical, real-world problem-solving. Despite growing interest in PBL, a comprehensive literature review has identified a significant gap: no specific studies have addressed the integration of AI in risk response actions for preparing undergraduate theses using PBL. Related studies presented at the PAEE/ALE'2023 and PAEE/ALE'2024 international conferences on active learning in engineering education identified potential risks and provided specific response actions to manage them. However, these studies did not explore the use of AI to optimize risk responses. Building on these findings, this study introduces a comprehensive set of AI-supported risk response actions to enhance the preparation of an undergraduate thesis in engineering. The research is anchored in a case study where students tackle real-world challenges faced by local companies, with PBL as the core framework. The study provides detailed tables outlining AI-enabled actions to mitigate risks at various stages of thesis preparation, ensuring effective management and reducing the likelihood of failure. By leveraging AI technologies such as advanced project management tools, research assistants, and communication platforms, the proposed actions optimize resources and significantly improve the overall quality of the undergraduate thesis. The findings demonstrate that AI can enhance the thesis preparation process for students, professors, and decision-makers involved in thesis supervision. Furthermore, this research establishes a robust framework for integrating AI into risk response strategies, paving the way for future advancements in engineering education and fostering a more streamlined and effective undergraduate thesis experience.

Keywords: Active Learning; Engineering Education; Project-Based Learning - PBL; Undergraduate Thesis; (AI) artificial intelligence

1 Introduction

Student-centered teaching methods, particularly Project-Based Learning (PBL), have become widely adopted in engineering education. However, despite its increasing popularity, universities often face unforeseen challenges when implementing PBL, sometimes leading them to revert to conventional lecture-based approaches (Henderson, 2012). One critical area of concern is the preparation of undergraduate theses, where various risk factors can influence the quality and success of final project reports. While existing literature extensively discusses the benefits of PBL, there is a significant gap in understanding and addressing the risks associated with undergraduate thesis failure, particularly in the context of risk mitigation strategies. Several recent studies have explored the impact of PBL on student learning and professional development. Kaeedi et al. (2023) compared the effectiveness of PBL and lecture-based learning (LBL) in teaching research methods, employing a mixed-methods approach. Lin et al. (2023) examined PBL as a means of reforming engineering education to foster innovation. Para-González et al. (2023) empirically assessed whether PBL enhances apprenticeship abilities and improves students' professional success. Leatemia et al. (2023) identified teacher profiles to understand their educational needs and the relationship between these profiles and previous PBL training. Despite these contributions, a critical gap remains regarding how PBL influences the quality and effectiveness of undergraduate thesis, particularly in collaboration with local companies. This study addresses that gap by identifying key risks in undergraduate thesis preparation within PBL frameworks and proposing

actionable strategies to mitigate these risks. The diversity of risk factors highlights the complexity of the process, emphasizing the necessity of effective risk responses. Failing to recognize and manage these risks can negatively impact students, professors, and partner organizations, ultimately compromising the anticipated benefits of PBL-based thesis projects. Moreover, this research explores the role of Artificial Intelligence (AI) in mitigating risks associated with undergraduate thesis preparation. AI-driven tools have the potential to enhance project planning, risk assessment, and quality control, ultimately improving the success rate of undergraduate final project reports (UFPR). Given the lack of comprehensive studies addressing risk assessment in undergraduate theses, this study aims to fill that gap by answering the following research questions: What are the actions to avoid or mitigate risks in PBL conducted in local companies during undergraduate thesis preparation? What AI actions can be used to avoid or mitigate risks during the preparation of Undergraduate Final Project Reports (UFPR)? By addressing these questions, the study contributes to improving the sustainability and effectiveness of PBL in engineering education, ensuring better outcomes for students and their academic institutions. The paper is organized into seven sections: the first introduces the context and problem, and the second presents studies about the use of IA in Undergraduate Final Projects. The third is the Theoretical Learning theories applied in the Undergraduate Final. Section 4 outlines the methodology, Section 5 presents the results, Section 6 discusses the results, and Section 7 concludes the study.

2 The Use of AI in Undergraduate Final Projects

Project-Based Learning (PBL) fosters critical thinking, collaboration, and problem-solving, vital for Undergraduate Final Projects (UFPs). Integrating Artificial Intelligence (AI), especially generative AI, enhances engagement, autonomy, and research outcomes. Palmer and Hall (2011) noted positive student responses to PBL in engineering, with AI addressing gaps through structured guidance and automation. Du et al. (2013) used PBL for sustainability education, where AI enables real-time data and simulations. García-Martín and Pérez-Martínez (2017) improved active learning with PBL, enhanced by AI adaptive systems. Marques (2018) emphasized formative monitoring, supported by AI analytics for progress tracking and peer reviews. Setiawan (2019) highlighted student-led topic selection, aided by AI tools like topic generators and writing aids. Moliner et al. (2019) analyzed PBL in Materials Science, where AI streamlines literature reviews and feedback. Schneider (2020) boosted engagement with PBL, enhanced by AI's personalized and gamified elements. Daun (2016) tailored PBL for academic levels, with AI providing level-specific support. Bhaskar et al. (2023) identified PBL barriers, mitigated by AI's task simplification. Merola et al. (2022) emphasized inclusive learning, supported by AI translation and accessibility tools. Nguyen et al. (2022) and Sousa et al. (2022) highlighted AI's role in digital transformation and institutional innovation. Pereira et al. (2022) noted that PBL with local companies is enhanced by AI project management and collaboration tools. Asril and Fathira (2025) showed AI's effectiveness in supporting English Literature students' writing and research. Sarhan et al. (2025) identified research barriers for dental students, mitigated by AI research assistants and mentorship. Hwang et al. (2025) guided AI-enhanced PBL, improving adaptability and digital fluency. AI streamlines research enhances engagement, and personalizes learning, making it essential for UFPs.

3 Theoretical Learning theories applied in Undergraduate Final Projects

Final Undergraduate Final Project Reports (UFPRs) are crucial for developing research skills, critical thinking, and professional readiness. They enhance institutional goals by improving learning outcomes, fostering reflection, and promoting a research-oriented culture. Haritha and Rao (2024) highlight experiential learning through Kolb's Cycle—concrete experience, reflective observation, abstract conceptualization, and active experimentation—where UFPRs allow students to reflect, conceptualize, and apply findings. Rohman et al. (2024) link Piaget's Cognitive Development Theory, noting that UFPRs help students construct knowledge through environmental interaction, demonstrating cognitive maturity via structured analysis. Ott (2024) applies

Bandura's Social Learning Theory, emphasizing self-efficacy as UFPRs encourage initiative, independent research, and time management—key to growth. Rosser and Sole (2024) underscore Schön's reflective practice, where UFPRs prompt critical evaluation of challenges and lessons, boosting problem-solving. Ilhami (2024) aligns UFPRs with Bloom's Taxonomy, spanning cognitive levels from understanding to creating insights, making them robust learning and assessment tools. UFPRs foster experiential learning (Haritha & Rao, 2024), conceptual understanding (Rohman et al., 2024), autonomy (Ott, 2024), reflective thinking (Rosser & Sole, 2024), and structured outcomes (Ilhami, 2024), bridging academic theory and real-world application for lifelong learning and professional success.

4 Methodology

The study adopted the approach of building theory from Case Study Research proposed by Eisenhardt (1989), and Yin, R. (2014). It combined data from archives, interviews, and observations in conducting PBL projects. The sample for the study was the PBL process utilized in the engineering course from the population of courses of a specific university. The number of stakeholders participating in the study is listed in Table 1.

Table 1. Stakeholders

Area	Function	Number of Participants	Average time of experience (years)
University	Engineering Students	3	4
Company	PBL leader focal point	1	20
	Employee member of PBL	1	25
University	Professors	2	10

These stakeholders were selected based on their expertise. The sample size is appropriate and significant since all the interested parties are covered. A process map was created to comprehend the variables involved, and a face-to-face interview was conducted to pinpoint details of the processes and the potential risks in each step. Data were collected from archives, interviews, and observations during the process. Risk factors were compiled by referencing existing literature and the process map. Participants, including students, professors, and organizational leaders, were surveyed to ascertain the probabilities associated with these risk factors. Ultimately, risk responses were formulated to address those risks identified by participants.

5 Results

This section shows the chart with the process groups involved in the Undergraduate Final Project Reports preparation, details of each process, the risks, the actions to mitigate or avoid the risks, and the proposed digital process to manage the processes presented in Figure 1 with the process's groups. The process groups were defined based on the Project Management Book of Knowledge (PMBOK) from PMI.

5.1 Processes Groups

The Processes Groups involved in preparing the Undergraduate Final Project Reports UFPR (**GFRP**) are presented in Figure 1.

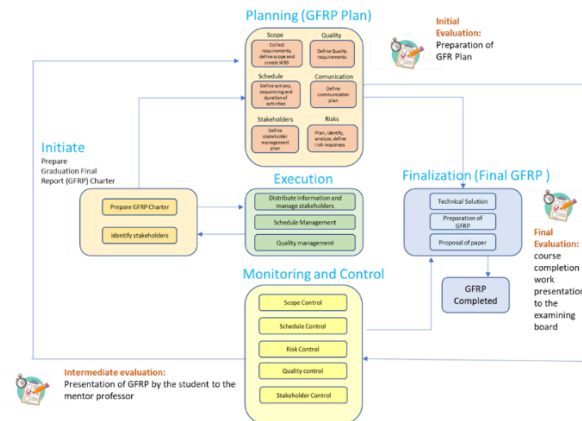


Figure 1. Process Management Groups

Figure 1 shows the processes in each phase of the report development. The GFRP Charter is prepared in the initiation phase, and stakeholders are identified. In Phase 2, the Planning (GFRP Plan) is prepared, starting with the scope (collect requirements, define the scope, and create WBS), then the schedule preparation (definition of actions, sequencing, and duration of activities), the definition of stakeholders (define stakeholder management plan), Quality plan (Define Quality requirements), Communication plan (Define communication plan) and finally the Risks identification (Plan, identify, analyze, define risk responses). Phase 3 is the Execution Phase, with the collection and distribution of information, management stakeholders, and the management of Schedule and Quality. In Phase 4, the monitoring and control happen, with the control of scope, risk, quality, schedule, and stakeholders. In Phase 5, the finalization of the GFRP, with the technical solution, preparation of the final GFRP, and paper. The Evaluation happens in three Steps. The first one is the Preparation of the GFR Plan; the second is the intermediate Evaluation with the presentation of GFRP by the student to the mentor professor and the Final Evaluation, with the course completion work (GFRP report) presentation to the examining board. The process must be documented in an electronic format, such as Google Form or another similar one.

5.2 Processes Details, Actions to avoid or mitigate risks, and AI Actions to avoid or mitigate risks

5.2.1 Initiation Processes Group

Tables 2 and 3 show the processes of the Initiation Processes Group, the actions to avoid or mitigate risks, and the AI Actions to avoid or mitigate risks.

Table 2 highlights how AI can support various project management actions effectively. To start with a well-defined project charter, AI writing assistants such as Grammarly or ChatGPT can draft and refine the language, ensuring that objectives, scope, and goals are clear and precise.

Table 2. Process – Prepare Charter

Process	Actions to avoid or mitigate risks	AI Actions to avoid or mitigate risks
Prepare Charter	Start with a well-defined project charter. Communicate effectively. Establish a realistic project timeline. Conduct thorough research. Stay organized.	A clear project charter sets a strong foundation. Templates ensure consistency, risk analysis spots challenges early. Effective communication boosts collaboration, with tools like translation, sentiment analysis, summaries, and chatbots enhancing discussions. Realistic timelines, accurate predictions, task prioritization, and updates enable adaptability. Thorough research, data discovery, summarization, trend analysis, and plagiarism detection ensure accurate, original insights. The organization improves efficiency via task management, reminders, document organization, and automation, keeping projects on track, reducing risks, and achieving goals effectively

Table 3 shows that by integrating the AI capabilities, students can streamline their workflow, reduce errors, and enhance the overall quality of their final project reports.

Table 3. Process – Identify stakeholders.

Process	Actions to avoid or mitigate risks	AI Actions to avoid or mitigate risks
Identify stakeholders	Have a well-defined process. Effective communication strategies. A proactive approach. Regularly update stakeholders. Seek their input when appropriate. Be prepared to adapt the project as needed. Consider involving an academic advisor.	AI enhances Undergraduate Final Project Reports (UFPR) by improving structure, clarity, and efficiency. AI tools generate outlines, identify risks, and provide report templates. Communication improves with AI writing assistants, meeting summaries, and academic chatbots. Risk management strengthens via plagiarism detection, predictive analytics, and scheduling tools for deadlines. Stakeholder engagement is streamlined with sentiment analysis, AI email drafting, and real-time collaboration with AI suggestions. Adaptability improves through trend analysis, smart reminders, and automated revision tracking. These AI capabilities streamline workflows, reduce errors, and elevate UFPR quality.

5.2.2 Planning Processes Group

Tables 4, 5, 6, 7, 8, and 9 show the processes that are part of the planning group, the actions to avoid or mitigate risks, and the AI Actions to avoid or mitigate risks. Table 4 shows the process scope planning and that by integrating AI into the project workflow, students can proactively manage risks, maintain effective communication, and improve the overall success of their undergraduate thesis.

Table 4. Process – Scope Planning

Process	Actions to avoid or mitigate risks	AI Actions to avoid or mitigate risks
Scope Planning	Ensuring that the scope is realistic and achievable. Define the purpose, goals, and expected outcomes. Research to understand the project. Collaborate with stakeholders. Clearly outline the deliverables and criteria for success. Implement a change control process. Conduct a realistic assessment of the time and resources. Assess the technical requirements. Identify and document risks. Define communication channels	AI aids Undergraduate Final Project Reports (UFPR) by boosting efficiency, clarity, and risk mitigation. AI tools define achievable project scopes by analyzing past projects, spotting feasibility issues, and suggesting improvements. AI research assistants speed up literature reviews, summarize findings, and identify knowledge gaps. Automated project management tools outline deliverables, track progress, and align with goals. AI risk analysis detects challenges, assesses requirements, and suggests mitigation. Intelligent scheduling optimizes timelines and resources with dynamic adjustments. AI collaboration platforms enhance stakeholder communication with automated summaries, sentiment analysis, and real-time feedback. AI also supports documentation by generating structured reports, ensuring clarity and academic compliance. Integrating AI helps students manage risks, communicate effectively, and enhance thesis success.

Table 5 shows the process of Quality planning and that by leveraging AI, students can refine their project scope, make data-driven decisions, and proactively address potential risks, leading to a more structured and successful undergraduate thesis.

Table 5. Process – Quality Planning

Process	Actions to avoid or mitigate risks	AI Actions to avoid or mitigate risks
Quality Planning	Carefully plan and define the scope, seek guidance from advisors, and Conduct a thorough literature review. Consider the feasibility, relevance, and objectives. Review and revise the scope.	AI enhances Undergraduate Final Project Reports (UFPR) by improving efficiency, accuracy, and risk management. AI research tools streamline literature reviews, summarizing findings, identifying gaps, and pinpointing relevant sources. Automated project management systems define project scope, analyze feasibility, set realistic objectives, and suggest revisions. AI writing assistants ensure clarity, coherence, and academic compliance, minimizing poorly structured reports. Predictive analytics identify challenges, keeping projects achievable. AI plagiarism detection ensures academic integrity, while smart scheduling and task management optimize time and prevent delays. By using AI, students refine project scope, make data-driven decisions, and address risks, ensuring a structured, successful thesis.

Table 6 shows the process of Schedule Planning and that by leveraging AI, students can manage time effectively, stay organized, and produce high-quality final reports with reduced risks.

Table 6. Process – Schedule Planning

Process	Actions to avoid or mitigate risks	AI Actions to avoid or mitigate risks
Schedule Planning	Create a realistic and flexible schedule, regularly update and adjust the schedule, Establish a consistent progress tracking system and complete your undergraduate final project report or thesis.	AI mitigates risks in Undergraduate Final Project Reports (UFPR) by enhancing scheduling, progress tracking, and research efficiency. AI project management tools create flexible schedules with automated reminders and adjustments. Predictive analytics spot delays and suggest proactive solutions. AI writing assistants improve clarity, coherence, and academic compliance, minimizing errors. Smart tracking systems monitor progress, generate reports, and highlight issues. AI research tools summarize the literature, identify gaps, and ensure originality via plagiarism detection. Using AI, students manage time, stay organized, and produce high-quality reports with reduced risks.

Table 7 shows the process of Communication Planning and that by leveraging AI, students can maintain effective, open, and structured communication throughout the project.

Table 7. Process – Communication Planning

Process	Actions to avoid or mitigate risks	AI Actions to avoid or mitigate risks
Communication Planning	Establish clear lines of communication. Maintain open, regular, and respectful communication. Seek feedback and address any issues. Effective communication.	AI improves communication and reduces risks in Undergraduate Final Project Reports (UFPR) with real-time translation, sentiment analysis, and automated summaries. AI writing assistants ensure clarity and coherence, while chatbots provide quick access to guidelines. Sentiment analysis identifies misunderstandings or negative feedback early for timely fixes. Automated transcription and summarization of document key points accurately. AI collaboration tools streamline advisor and peer communication, ensuring consistent feedback and progress tracking. Using AI, students maintain effective, structured communication throughout the project.

Table 8 shows the process of Stakeholder Planning and that by leveraging AI, students can maintain effective, structured, and continuous communication, minimizing risks related to misinterpretation and lack of guidance.

Table 8. Process – Stakeholder Planning

Process	Actions to avoid or mitigate risks	AI Actions to avoid or mitigate risks
Stakeholders Planning	Establish clear lines of communication. Maintain open, regular, and respectful communication. Seek feedback and address any issues. Effective communication.	AI mitigates risks in Undergraduate Final Project Reports (UFPR) by improving communication and feedback. AI writing assistants ensure clarity and coherence, while automated summaries and real-time translation aid collaboration with advisors and peers. Sentiment analysis detects misunderstandings for quick resolution. AI chatbots offer instant answers, reducing guidance delays. AI-driven transcription captures key discussions, ensuring feedback is documented and addressed. Using AI, students maintain effective, structured communication, minimizing risks of misinterpretation and lack of guidance.

Table 9 shows the process of Risk Planning, and that sentiment analysis improves communication by identifying concerns early, ensuring transparency with stakeholders, and fostering a structured approach to risk management.

Table 9. Process – Risk Planning

Process	Actions to avoid or mitigate risks	AI Actions to avoid or mitigate risks
Risks Planning	Conduct thorough risk identification and assessment. Prioritize risks. Develop clear mitigation strategies. Regularly review and update risk management plan. Effective communication and transparency with stakeholders	AI can enhance risk management in Undergraduate Final Project Reports (UFPR) by automating risk identification, assessment, and mitigation. AI-powered data analysis can detect potential issues based on past research patterns, while predictive analytics help prioritize risks by assessing their likelihood and impact. AI-driven project management tools assist in developing and updating mitigation strategies, ensuring proactive responses to challenges. Automated monitoring systems track project progress and highlight deviations from the plan, enabling timely adjustments. Additionally, AI chatbots and sentiment analysis improve communication by identifying concerns early, ensuring transparency with stakeholders and fostering a structured approach to risk management.

5.2.3 Execution Processes Group

Tables 10, 11, and 12 show the processes that are part of the execution group, benefits/success factors, what could go wrong, and the consequences and actions to avoid or mitigate issues. Table 10 shows that AI also ensures content consistency and analyses feedback to identify concerns early, improving overall project efficiency and quality.

Table 10. Process – Distribute information and manage stakeholders

Process	Actions to avoid or mitigate risks	AI Actions to avoid or mitigate risks
Distribute information and manage stakeholders.	Establish clear communication channels. Define roles and responsibilities. Regularly update stakeholders. Have a well-defined project plan.	AI aids Undergraduate Final Project Reports (UFPR) by mitigating risks and ensuring progress. AI project management tools track tasks and deadlines, while document review tools check grammar, citations, and plagiarism. Predictive analytics optimize resource allocation for research and revisions. Automated communication tools update stakeholders, reducing miscommunication. AI risk assessment predicts issues for proactive solutions. Version control prevents draft loss, and research tools recommend relevant materials. AI ensures content consistency and analyzes feedback to address concerns early, boosting project efficiency and quality.

Table 11 shows the process Schedule Management and that AI-driven risk management tools can identify potential issues early, offering suggestions to mitigate them before they impact the project's progress.

Table 11. Process – Schedule Management

Process	Actions to avoid or mitigate risks	AI Actions to avoid or mitigate risks
Schedule Management	Regularly reassess and adjust your schedule. Communicate effectively with project stakeholders. Practice good time management habits. Flexibility and adaptability	AI enhances Undergraduate Final Project Reports (UFPR) by mitigating risks and improving project management. AI tools track progress, adjust timelines, and send deadline reminders, ensuring adaptable schedules. AI communication tools, like chatbots and automated emails, provide timely stakeholder updates, minimizing misunderstandings. AI task prioritization optimizes time allocation for critical tasks. Predictive insights from AI foster flexibility, enabling adjustments to challenges or shifting priorities. AI risk management tools identify issues early, suggesting mitigations to maintain project progress.

Table 12 shows the process of Quality Management, and the actions reduce the risk of confusion, missed deadlines, and misalignment, promoting smoother project completion.

Table 12. Process – Quality Management

Process	Actions to avoid or mitigate risks	AI Actions to avoid or mitigate risks
Quality Management	Provide comprehensive guidance. Clear expectations. Well-defined objectives. Effective communication	AI aids Undergraduate Final Project Reports (UFPR) by mitigating risks and keeping projects on track. AI tools provide structured templates and guidelines that meet academic standards. AI project management systems outline milestones, deadlines, and deliverables, aligning student and supervisor goals. AI analyzes project scope, breaking it into manageable tasks and suggesting report structures. AI communication platforms send automated updates and reminders, keeping stakeholders informed. These actions minimize confusion, missed deadlines, and misalignment, ensuring smoother project completion.

5.2.4 Monitoring Processes Group

AI enhances monitoring and controlling Undergraduate Final Project Reports, ensuring efficiency, quality, and objective adherence. AI project management tools track progress, update milestones, and flag delays, while predictive analytics identify risks and suggest mitigations. AI optimizes task prioritization, workload, and resource use. Grammar, plagiarism, and content analyzers ensure academic integrity and writing quality. Automated compliance checks detect scope deviations. AI chatbots and virtual assistants aid communication, with transcription and summarization tools streamlining feedback. Data-driven insights guide research by analyzing past outcomes. AI improves advisor satisfaction by analyzing feedback trends. It flags workflow bottlenecks, suggests solutions, and provides personalized insights on writing, research, and organization, recommending improvements. Using AI, students boost efficiency, reduce errors, and ensure successful project completion through adaptive planning and assessments.

5.2.5 Closure Processes Group

AI streamlines Undergraduate Final Project Report closure by enhancing documentation, evaluation, and transition. AI writing assistants refine reports for clarity, coherence, and formatting, while grammar and plagiarism tools ensure integrity. Automated review tools fix inconsistencies, improve structure, and validate citations. AI analytics evaluate project data, assess objectives, and highlight findings. AI summarization tools document lessons learned, extracting key insights. Chatbots and sentiment analysis gather structured feedback from advisors and stakeholders. AI presentation tools optimize defense slides, suggest key points, and simulate questions. Sentiment analysis assesses advisor and client satisfaction, informing future projects. AI document systems ensure organized archiving. Compliance tools uphold ethical standards, like data privacy. AI career tools suggest research or job paths based on outcomes. AI-generated reports celebrate achievements, marking

a meaningful conclusion. Using AI, students boost efficiency, ensure thoroughness, and gain insights for academic and professional success.

5.3 Digital Process

AI streamlines record-keeping for Undergraduate Final Project Reports by enhancing organization, accessibility, and security. AI document management systems categorize and tag files, enabling efficient retrieval via intelligent search. NLP analyzes content, generating metadata and summaries. Automated workflows track deadlines, monitor progress, and notify stakeholders. AI collaboration tools integrate version control, annotations, and feedback for seamless communication. Machine learning analyzes records to identify trends and suggest improvements. AI plagiarism detection ensures integrity, while compliance checks verify guideline adherence. AI enhances security with encryption, access control, and anomaly detection. Integrating AI with thesis management systems fosters independent project management, streamlines supervision, and prepares students for data-driven, collaborative work environments.

6 Discussion of Results

This study developed a process map for Project-Based Learning (PBL) in undergraduate theses, collaborating with local companies to address challenges for students, faculty, and industry partners. Proactive risk management, as shown in risk assessment tables, enhances final project report quality, reduces student stress, and boosts achievement. Anticipating challenges strengthens analytical, synthesis, and evaluation skills, vital for problem-solving and data communication, preparing students for graduate studies or research careers. Final project reports assess engineering concept mastery and real-world application. The structured framework fosters academia-industry collaboration, positioning research as practical problem-solving. A clear project charter, defining scope, objectives, planning, resource allocation, and communication, ensures systematic, results-driven thesis work, equipping students with professional project management skills. Professors act as facilitators, guiding scoping, ethics, timelines, feedback, and defense preparation, fostering a supportive academic environment aligned with industry needs. AI-driven tools, including predictive analytics, automated feedback, and real-time tracking, can further optimize risk management, enhancing efficiency and effectiveness in thesis preparation. This study advances sustainable PBL methodologies in engineering education, improving outcomes for all stakeholders.

7 Conclusion

This study addresses a literature gap by examining risk management in PBL with local companies for undergraduate theses, answering two questions: What actions mitigate risks in PBL thesis preparation? How can AI support risk mitigation in Undergraduate Final Project Reports (UFPR)? For the first, it identifies risks and proposes preventive measures, improving report quality, reducing stress, and enhancing university-industry collaboration. For the second, AI tools streamline project management, data analysis, and feedback, enabling early risk detection and better decision-making. Unlike prior studies, this research focuses on optimizing thesis preparation through risk management and AI integration. The adaptable methodology improves educational outcomes and institutional reliability. Future research can explore AI's broader role in engineering education, refining methods to lower thesis failure rates. Combining structured risk management with AI innovations fosters an efficient, data-driven academic environment, benefiting students, faculty, and industry.

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AxoloBot: Design and Development of a Bioinspired Robot Based on a Modular Platform

Daniel Arriaga-Ventura¹, Israel Ulises Cayetano-Jiménez¹, Rogelio Bustamante-Bello¹

¹ School of Engineering and Sciences, Tecnológico de Monterrey, Mexico City, Mexico

Email: a01338696@tec.mx, israel.cayetano@tec.mx, rbustama@tec.mx

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Abstract

This study presents AxoloBot, a modular robotic platform inspired by the axolotl (*Ambystoma mexicanum*), developed to support both research in multimodal locomotion and the practical teaching of control strategies in complex dynamic systems. The primary objective was to create an educational tool that effectively bridges theoretical instruction with hands-on experimentation. The development process began with a morphological and locomotor analysis of the axolotl, which guided the mechanical design of hybrid limbs integrating crank-rocker and wheg mechanisms to reproduce crawling and walking gaits observed in the biological model. The robot's components were modelled in CAD and fabricated using PLA-based 3D printing. A Proportional-Derivative controller was implemented on an ESP32 microcontroller to maintain a 180° phase offset between rear limbs, enabling stable and coordinated gait generation under typical use conditions. To assess its pedagogical potential, AxoloBot was integrated into an undergraduate control systems activity involving four students, who configured control parameters and analysed system behaviour in real time. Preliminary observations indicated improved comprehension of control principles and greater student engagement. A broader classroom deployment is planned to evaluate its long-term educational impact. AxoloBot represents a modular platform with potential applications in both robotics research and engineering education.

Keywords: Bioinspiration; Axolotl; Robotics; Multimodal locomotion; Research tool.

1 Introduction

Through evolution, living organisms have developed the ability to adapt by refining their physical characteristics, internal systems, and chemical structures to overcome environmental challenges. These adaptations serve as a repository of biological wisdom applicable across a wide range of disciplines (Primrose, 2020). Among these, the field of robotics has particularly benefited from biological inspiration, using natural organisms as models to design systems that replicate their key features. This approach contributes to enhanced performance, adaptability, and functionality in robotic platforms.

One example of this bioinspired approach is found in Central Pattern Generators (CPGs), which are small neural networks present in living organisms that generate rhythmic movements, such as walking, flying, or swimming, without direct supervision from the brain (Purves, 2018). These networks have been widely studied and implemented in robotics, enabling systems to produce several types of locomotion by modulating parameters such as frequency, amplitude, and phase shifts between signals. This capability provides more robust, efficient, and flexible solutions for robotic locomotion (Hogan & Sternad, 2007; Ijspeert, 2008). A notable application of this principle is found in the Salamandra Robotica II, a bioinspired platform that integrates CPGs to reproduce salamander-like gaits, showcasing effective transitions between swimming and walking in aquatic and terrestrial environments (Crespi, Karakasiliotis, Guignard, & Ijspeert, 2013).

Despite their versatility, CPGs present significant challenges due to their nonlinear dynamics and reliance on heuristic parameter tuning (Yu, Tan, Chen, & Zhang, 2014). To address these challenges, bioinspired robotic platforms can serve as educational tools for understanding CPGs, providing an experimental environment in

which complex robotic systems imitate biological locomotion. Through this approach, it is possible to gain insights into the behaviors and properties associated with different CPG architectures and parameter configurations. Additionally, these platforms support the teaching of control concepts such as variable selection, controller tuning, and performance assessment in real-world applications. By integrating CPGs with conventional control strategies, they help bridge the gap between theory and practice in STEM education (Kopman & Porfiri, 2011).

In response to this educational and scientific need, the present study proposes the development of a robotic platform inspired by the axolotl, an amphibian native to Mexico renowned for its regenerative capacity and neoteny (Gresens, 2004). Beyond its biological relevance, the axolotl exhibits functional characteristics of particular interest in robotics. Its locomotion combines spinal oscillations, tail propulsion, and limb coordination, enabling efficient swimming and supporting two underwater gaits, crawling and walking, making it a valuable model for studying multimodal locomotion. In addition to its scientific importance, the species is critically endangered, prompting conservation initiatives such as the program led by CONABIO in Xochimilco (Parrodi, 1999). Given this status, a robotic platform could facilitate low-intrusion ecological studies of its natural habitat, supporting conservation efforts and research on its exceptional regenerative abilities.

The proposed robotic platform fulfills two complementary purposes: it functions as an educational and experimental tool for the implementation and study of CPG-based control strategies in systems with six degrees of freedom, while also representing an initial step toward the development of a fully biomimetic robotic system that could support less intrusive in-situ biological research. This article begins by describing the biological basis of the project, including the morphological, structural, and locomotion characteristics of the axolotl. It then presents the mechanical design, with a focus on limb development, followed by a brief overview of the electronics and firmware. Finally, the results related to mechanical performance and locomotion are discussed, concluding with insights and future research directions.

2 Anatomy and Morphology

In order to accurately obtain the dimensions of the axolotl's body, we referred to a research study titled *Morphometric Description of the External and Internal Anatomy of Ambystoma mexicanum* (Ramírez-Macal, Chávez-Ríos, Velasco-Reyes, & Díaz, 2023). This study presents the average measurements collected from two male and three female specimens, as detailed in Table 1.

Table 1. Axolotl parameters and dimensions.

Assessed parameters	Average	Standard deviation
Weight [g]	31.6	6.88
Mandibular symphysis to tail tip length [cm]	15.70	1.96
Mandibular symphysis to cloaca length [cm]	8.30	0.97
Mandibular symphysis to cloaca length [cm]	1.72	0.27
Transverse length [cm]	2.36	0.21
Forelimb length [cm]	2.92	0.24
Hindlimb length [cm]	2.88	0.35

In addition to the anatomical measurements, the external morphology of the axolotl was examined to identify functional traits relevant to bioinspired design. This analysis, conducted through literature review and direct observation of a living specimen, aimed to extract features that could inform the robot's structure and locomotion.

One of the most distinctive elements is the presence of external gills, three branch-like structures on each side of the head, covered with filaments essential for gas exchange (Gresens, 2004). Another significant trait is its jelly-like skin, which improves surface adhesion, contributing to greater stability and maneuverability underwater. The skin also presents a variety of pigmentation patterns, such as black, mottled brown, white, and albino.

Additional features include four limbs ending in small fingers and a long tail with a dorsal fin-like extension. These elements allow different modes of aquatic locomotion, allowing the axolotl to swim, walk short distances underwater, and crawl along submerged surfaces.

3 Displacement Characteristics

In order to abstract the main elements of the axolotl's locomotion, observations and video recordings were conducted at the Axolotl Museum in Xochimilco, a centre dedicated to the species' conservation and research. The study employed non-intrusive methods, avoiding any physical handling of the specimens to preserve their natural behaviour. As a result, three distinct gaits were identified, crawling, walking, and swimming, along with their corresponding coordination patterns involving the limbs, tail, and spine. All these locomotion modes occur exclusively in aquatic environments, as axolotls are fully aquatic amphibians.

Based on the recorded observations, the first gait analysed was crawling, in which the axolotl moves on its belly, with diagonal limbs moving in a symmetrical swaying pattern, while the spine and tail oscillate with an approximate 180° phase offset. This gait closely resembles the crawling pattern of *Pleurodeles waltl*, which served as a reference for the design of the Pleurobot (Karakasiliotis, et al., 2016). Walking shares the same coordination pattern as crawling, but with a greater range of motion in the limbs, which support most of the body weight due to buoyancy, allowing a lifted posture and more controlled steps. In swimming, the limbs remain close to the body to reduce drag, and propulsion is produced by a propagating wave motion of the spine and tail, similar to the swimming behaviour of *Pleurodeles waltl* (Karakasiliotis, et al., 2016).

4 Mechanical Design

The mechanical design of AxoloBot is inspired on the anatomical elements and locomotion patterns of the axolotl. The development process included several iterations using CAD modelling and 3D printing. The robot is composed of modular parts such as limbs, spine, tail, head, and a central body, each designed to perform specific functions while maintaining ease of assembly. Particular attention was given to replicating crawling and walking movements through the integration of mechanical linkages and adaptable components.

4.1 Limbs design

This study focuses on replicating two of the axolotl's three locomotion modes, crawling and walking, using a single mechanical system. To achieve this, two complementary mechanisms were selected based on their kinematic characteristics: a crank rocker mechanism for crawling and a whleg mechanism for walking. These mechanisms were integrated into a unified limb structure capable of switching between gaits. The design process was iterative, with progressive refinements made to improve geometry and functionality. A key element enabling this versatility is a mechanical switching system that employs an L-shaped shaft, mounted on the

second largest link. This shaft allows the link to be detached from the fixed bar and reattached to the smallest link, enabling the mechanism to transition from crank rocker to wheg configuration. This design allows for the reconfiguration of locomotion modes with minimal alterations to the mechanical structure.

In the crawling configuration depicted in Figure 1, the crank rocker mechanism generates a partial circular trajectory that mimics the contact motion observed in biological crawling. The path resembles a crescent moon, enabling the limb to apply forward force at the lowest point while avoiding surface contact at the highest. This movement is suited for low-amplitude, near-ground propulsion.

In the walking mode shown in Figure 2, the wheg mechanism produces a larger, circular trajectory with symmetrical movement of 40 mm along both the X and Y axes. This increased amplitude allows the robot to clear small underwater obstacles more effectively. Notably, forward motion in this configuration requires the motor to rotate in the opposite direction compared to the crawling mode.

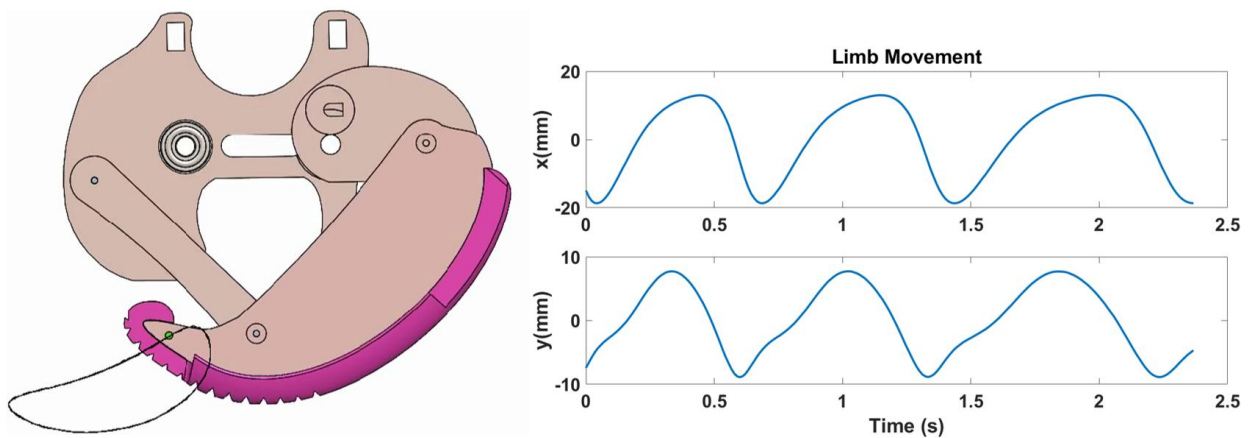


Figure 1. Simulated crawling trajectory of the limb driven by a crank-rocker mechanism.

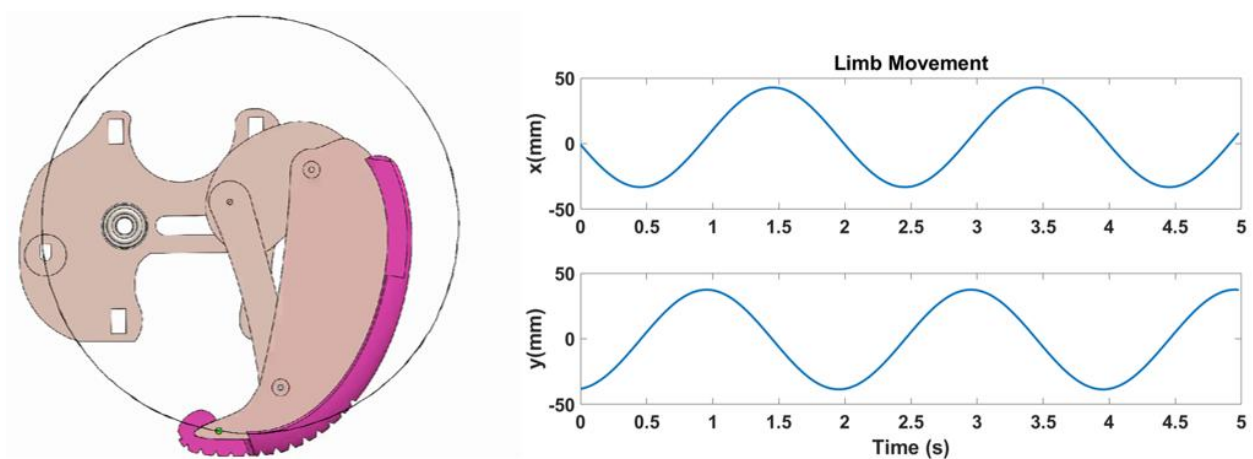


Figure 2. Simulated walking trajectory of the limb driven by a wheg mechanism.

The final prototype was manufactured using PLA for the structural components via 3D printing. 1 mm steel axles and 1 mm metal bearings were used to enhance rotational movement at the joints. Additionally, the largest link in each limb was fitted with a rubber cover designed to imitate the axolotl's skin texture, improving grip and stability during contact with submerged surfaces.

4.2 Central Body Module

The central body module serves as the structural and functional core of AxoloBot. It supports the attachment of two limbs, one on each side, houses the main PCB, and provides alignment for the drive system. The design integrates mounts for Pololu gearmotors, structural supports for limb suspension, and double helical gears that transmit power from the motor to the limbs with a 2:1 reduction ratio. Its configuration ensures modular connectivity and compact integration of mechanical and electronic components. The module was 3D printed using UV-sensitive resin.

4.3 Modular Mechanism

To promote simplicity and reusability, a modular bevel gear system was designed for the head, spine, and tail. The gear train uses a 1.5:1 reduction ratio to increase torque while maintaining a compact layout. The mechanism includes a Pololu™ ball caster to support crawling motion, along with opposing bearings that guide a cable-based push-pull system. This configuration enables directional locomotion through continuous motor rotation, eliminating the need for motor reversal and simplifying actuation.

4.4 Limb Suspension

A dual-spring suspension system was implemented to maintain ground contact and improve adaptability to uneven terrain. The mechanism consists of two springs mounted around a rotating axle that holds the motor housings, one stronger spring positioned below and a weaker one above. This configuration allows the axle, and consequently the legs, to rotate slightly in response to surface variations. As a result, the legs can adjust their angle of attack passively, improving terrain adaptability while maintaining stability and continuous contact with the ground.

4.5 Tail

The tail is actuated via two side-attached cables connected to the modular mechanism. The system operates through a push-pull configuration, enabling undulatory motion by alternately pulling and pushing each side of the tail. The tail itself is made of Shore 20A silicone rubber, providing the flexibility needed for smooth deformation. Its structure includes interlocking base protrusions for alignment and lateral cutouts to reduce weight while maintaining structural integrity.

4.6 Spine

The spine consists of three compliant elements made of Shore 20A silicone rubber that connect the central modules in sequence. The central piece, smaller in size, is anchored to two modular mechanisms: one containing the bevel gear system that drives cable-based push-pull actuation for generating undulatory motion, and the other providing structural support. The two lateral elements connect to the sides of the modules, reinforcing the overall structure and contributing to the visual coherence of the design.

4.7 Head

The design of the head was conceived with the primary objective of integrating sensors to capture essential environmental data and facilitate communication with the various microcontrollers distributed throughout the body. To this end, a designated cavity was crafted within the head, paired with a shaft to house a gear from the modular mechanism, thus enabling the capability for movement. However, due to time constraints, our implementation efforts were limited to the structural model of the head and the installation of the gear.

4.8 Final Design

The final design of AxoloBot, depicted in Figure 3, integrates features inspired by the anatomy and locomotion of the axolotl. The robot is modular, allowing for easy disassembly and rapid replacement of components. Its limbs can switch between crawling and walking modes through a reconfigurable mechanism. The suspension system provides terrain adaptability, while the compliant silicone tail and articulated spine enhance movement fluidity. The central module houses the electronics and supports all actuators, enabling compact integration.

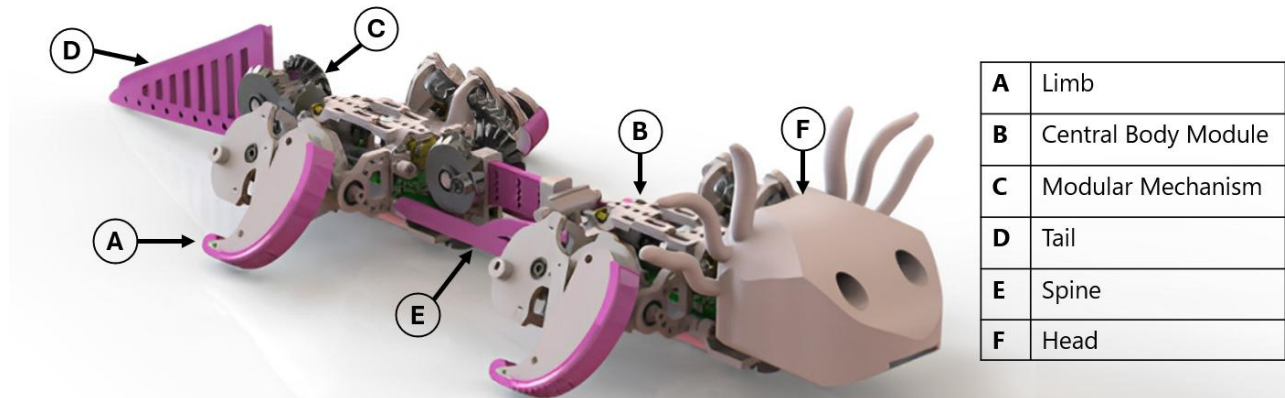


Figure 3. AxoloBot final design

5 Electronics

The electronic system is centred around a custom PCB designed by co-author Israel Cayetano, responsible for motor control and communication. The board integrates an ESP32-PICO microcontroller, DRV8231A motor drivers, a 6 V power input, and JST-SH connectors for UART, I²C, and motor/encoder interfaces. The PCB distributes power, generates PWM control signals, and reads feedback from motor encoders.

The actuation system employs Pololu 6V Micro-Metal Gearmotors (150.58:1 reduction), offering 2 kg·cm stall torque and compact dimensions (10×12 mm). Each motor is paired with a Pololu magnetic quadrature encoder, providing 12 counts per revolution and operating within a 2.7–18 V range. The six-pin JST-SH connector enables power, signal, and motor connection in a compact layout.

6 Firmware

The control architecture was designed to ensure coordinated locomotion by maintaining consistent phase offsets between the limbs, spine, and tail. To this end, an initial evaluation of the control variable was conducted, comparing speed and position. Speed control, which relies on maintaining continuous motor rotation, was found to be prone to phase offset loss when external disturbances or obstacles are present. As a result, angular position was selected as the control variable, since it continuously seeks to reach the reference position, preserving coordination even under perturbations.

Based on this decision, the firmware was developed to implement angular position control through a Proportional-Derivative (PD) controller. The control process begins with the generation of reference signals by oscillators, which define the target angular positions for each joint. These references are compared with the measured positions obtained from quadrature encoders to calculate the control error. The error is then processed by the PD controller, whose output determines the corresponding PWM signal. This signal is applied to the motors through an H-bridge to execute the desired motion. This control logic was implemented using

an object-oriented programming approach, resulting in a modular firmware architecture. The following list outlines the libraries used in its implementation.

- Oscillator: Generates reference positions and provides the 180° phase shift.
- Encoder: Captures angular position using quadrature signals.
- PWM: Regulates the motor's power via duty cycle control.
- Controller: Implements PD control to compute the appropriate duty cycle.
- H-Bridge: Sets motor direction and applies PWM input.
- Servo: Integrates the above libraries to simplify limb control.

7 Results and Discussion

Figure 4 compares the dimensions of a mature male axolotl and the AxoloBot. The robot's body length is scaled 1.5 times, the tail is 0.77 times shorter, and limb spacing is increased by a factor of 3.07. These disproportions result from constraints such as motor size and component layout. While functional, they indicate the need for future morphological adjustments to enhance fidelity and enable less intrusive field deployment.

In addition to morphological assessment, structural performance was evaluated through static simulation using Von Mises stress analysis. The simulation considered a load equivalent to half the robot's total mass (410g), representing a typical scenario in which one limb supports the body during stance. All critical components remained well below the PLA yield range (55–72 MPa). The limb, which bears the entire support load during propulsion, exhibited the highest stress level, reaching a maximum of 2.92 MPa. These results confirm that the robot's mechanical structure can safely support its own weight and endure routine mechanical impacts.

Moreover, the control system was evaluated by analysing the angular response of the rear limb motors in crawling mode (Figure 5). The results confirm that the system maintains the required 180° phase offset between the limbs, ensuring proper gait coordination. However, Motor 1 showed slower convergence and a noticeable overshoot around 4000 ms, caused by internal friction or a brief mechanical obstruction. Initial delays and overshoot were observed, due to static friction and mechanical tolerances, suggesting areas for future refinement.

In summary, the control system achieves stable phase coordination with minimal deviation from reference trajectories, validating the robot's design. While improvements in mechanical tolerance and adaptability are planned, AxoloBot has already been used in a hands-on activity with four undergraduate students. During this activity, they selected control variables and tuned PD parameters, reinforcing their understanding of locomotion control through direct experimentation. A classroom trial is planned to further assess its educational effectiveness in teaching system dynamics and robotic coordination.

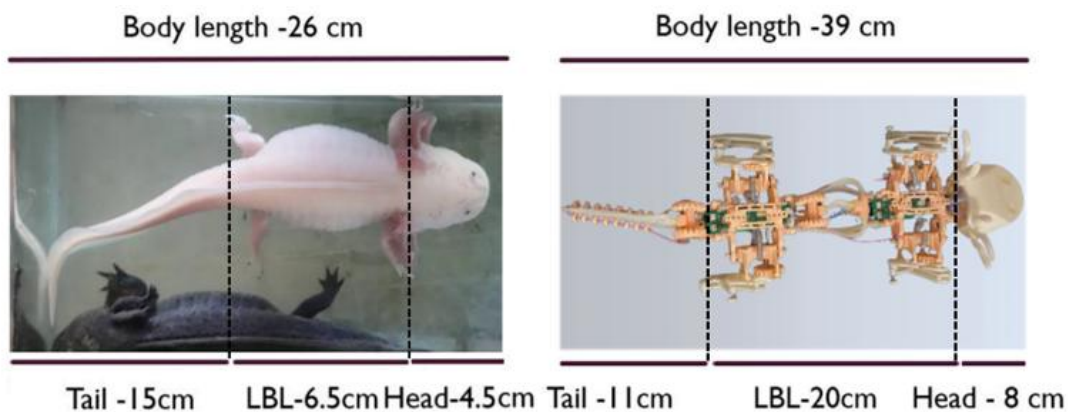


Figure 4. Mexican axolotl and Axolobot dimensions comparison

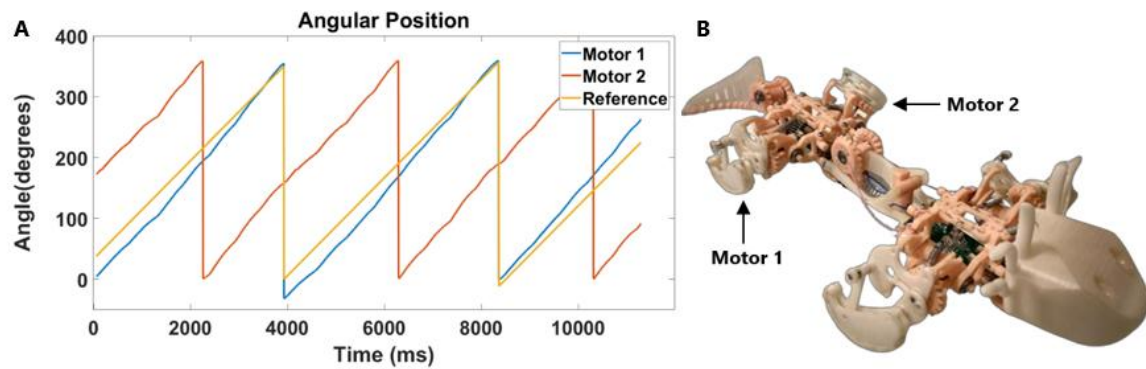


Figure 5. (A) Motors' angular position versus reference. (B) Robot configuration showing motor locations during crawling.

8 Conclusion

This work presented the development of a bioinspired robotic platform modelled after the axolotl, with emphasis on structural design, proportion analysis, and low-level control strategies. Finite element simulations confirmed that the mechanical structure remains within safe stress limits under expected loading conditions, validating its suitability for experimental use.

Although the current prototype achieves functional locomotion, discrepancies in body proportions relative to a mature axolotl limit its morphological fidelity. Additionally, the current model requires manual intervention to switch between locomotion modes. A future redesign will address these limitations by refining limb geometry, improving surface contact to reduce slippage, implementing an automatic mode-switching mechanism, and redistributing the electronic components to achieve body proportions more closely aligned with those of the real specimen.

In parallel, the control system was tested in a design activity involving four undergraduate students, who tuned PD parameters and observed coordination behaviour. This experience demonstrated AxoloBot's value as an educational platform for robotics and control. A classroom trial is under development to evaluate its impact on student understanding of hybrid locomotion and system dynamics.

Moreover, experimental results demonstrated the robot's capacity to perform two coordinated gaits with acceptable position tracking. Nevertheless, to improve robustness against disturbances, the integration of CPGs is proposed. In particular, Matsuoka-based CPGs with sensory feedback, as explored in prior studies (Fukuoka, Kimura, & Cohen, 2003), offer a promising approach to enhance adaptability and gait stability in dynamic environments.

Future efforts will focus on parameterizing the CPG model based on empirical data from axolotl locomotion, considering gait amplitude, frequency, and inter-limb phase offset, and on exploring neural modulation for adaptive gait control (Harris-Warrick, 2011). Additional developments include sensor integration for environmental data acquisition and autonomous navigation, inspired by aquatic platforms such as AQUA (Dudek, y otros, 2007). Waterproofing solutions will be explored to enable full underwater operation, including the implementation of a Dragon Skin silicone suit, selected for its flexibility, durability, and resemblance to the texture of axolotl's skin.

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Which Transferable Skills do Students Acquire in PBL? Insights from the Industrial Engineering and Management Course

Inês Silva¹, Beatriz Silva¹, Marta Ribeiro¹, Violeta Carvalho^{2,3,4,5}, Cristina S. Rodrigues², Ângela Silva², Anabela Alves², Carina Pimentel², Rui M. Sousa², Senhorinha Teixeira²

¹ Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal

² ALGORITMI/LASI Research Center, School of Engineering, University of Minho, Guimarães, Portugal

³ Mechanical Engineering and Resource Sustainability Center (MEtRICs), University of Minho, Campus de Azurém, Guimarães, Portugal

⁴ Center for MicroElectromechanical Systems (CMEMS UMinho), University of Minho, Campus de Azurém, Guimarães, Portugal

⁵ LABBELS—Associate Laboratory, 4806-909 Braga/Guimarães, Portugal

Email: a104681@alunos.uminho.pt, a104680@alunos.uminho.pt, a104773@alunos.uminho.pt, violeta.carvalho@dps.uminho.pt, crodrigues@dps.uminho.pt, asilva@dps.uminho.pt, anabela@dps.uminho.pt, carina.pimentel@dps.uminho.pt, rms@dps.uminho.pt, st@dps.uminho.pt

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Abstract

Project-based learning (PBL) methodologies have been used for two decades in Industrial Engineering and Management (IEM) programs of the Department of Production and Systems of the School of Engineering at the University of Minho. During the bachelor program, the students are engaged in three major projects, one during each year. They are called Integrated Projects (IPs) because all of them integrate the Curricular Units of the semester and they run under the PBL methodology. Teachers enrolled in these projects believe that those IPs not only facilitate the development of the technical skills of the Project Supporting courses but also are the more suitable way of providing students with abilities to learn and apply this knowledge. Additionally, teamwork and solving real problems are aspects that will enhance student performance in future professional contexts. These so-called transferable skills can make a difference and contribute significantly to the success of IEM students. Different teachers from the three IPs previously evaluated the most frequently cited transferable skills and the extent to which these skills are considered in each IP. In the present work, a previous exploratory study (on teachers' perceptions about transferable skills acquisition) is updated exploring the students' feelings and perceptions of the acquisition of the considered set of transferable skills. A survey taken of the 3rd year students was used to identify the main aspects to be improved in each IP project of the 1st and 2nd year of the bachelor's degree. The results reveal a quite positive perception of the students regarding the development of transferable skills, but also pointed out some improvement opportunities.

Keywords: Project Based Learning; Students Perspective; Transferable Skills

1 Introduction

Project-based learning (PBL) has established itself over the past decades as an effective pedagogical methodology in higher education, especially in fields with a strong practical component such as Industrial Engineering and Management (IEM). In the context of the University of Minho, the use of PBL in the Integrated Projects (IP) of the IEM bachelor's degree program highlights a commitment to an educational approach that seeks not only to develop technical skills but also a broad set of transferable skills essential for the professional world.

These Integrated Projects, carried out each year of the bachelor's degree at the University of Minho, integrate the various curricular units of the corresponding semester, encouraging students to work in teams and solve real-world problems, thus promoting a more active learning experience. Studies such as those by Helle et al. (2006) and Alves et al. (2017) indicate that PBL facilitates the development of skills such as communication, critical thinking, time management, and the ability to work in interdisciplinary contexts, all highly valued in today's labour market.

The literature has reinforced the importance of acquiring transferable skills in engineering education. According to Prince & Felder (2006), these skills are crucial for graduates to adapt to dynamic and multidisciplinary work environments. Furthermore, the integration of real-world projects into the academic curriculum offers students a unique opportunity to apply theoretical knowledge in practical situations, increasing their motivation and promoting both personal and professional development (Lavado-Anguera et al., 2024).

However, while the benefits of PBL in fostering transferable skills are well documented, its implementation also presents notable challenges, particularly in collaborative dynamics. As highlighted by Hussein (2021), students often face difficulties in coordinating tasks, managing interpersonal conflicts, and maintaining equitable contributions within project teams. Addressing these issues is essential to ensure that the full potential of PBL in skill development is effectively realized.

Building on a previous exploratory study that evaluated the most frequently cited transferable skills by teachers involved in the IPs (Carvalho et al., 2024), the present work updates that analysis by incorporating third-year students' perceptions regarding the acquisition of these skills throughout the projects of the first and second years. A specific questionnaire was used to identify the main strengths and areas for improvement in each project, providing insights into the evolution of skill development along the academic path.

Thus, this paper is organized into four sections. The first is dedicated to the study context, describing the implementation of the Integrated Projects in the Industrial Engineering and Management program at the University of Minho and the importance of transferable skills. The second section presents the adopted methodology, including the characterization of the questionnaire and the profile of the participants. In the third section, the main results obtained are presented and discussed, focusing on students' perceptions of skill development throughout the projects. Finally, the fourth section presents the study's main conclusions, highlighting the identified areas for improvement and suggesting future directions for strengthening the acquisition of transferable skills within the academic journey.

2 Study Context

The integration of Project-Based Learning (PBL) at the University of Minho, within the Department of Production and Systems (DPS), dates back to the 2004/2005 academic year. At that time, Industrial Engineering and Management (IEM) students were introduced to an interdisciplinary project designed to provide a dynamic learning environment, where they could apply theoretical knowledge to real-world problems, developing both technical expertise and key transversal skills such as teamwork, problem-solving, and project management (Lima et al., 2007).

Since then, this approach to IEM education has evolved, but it was only formally incorporated into the curriculum in 2021. The introduction of the Integrated Project in Industrial Engineering and Management (IPIEM) as part of the course curricular structure marked a significant milestone, consisting of three separate curricular units (IPIEM I, II, and III), one for each year of the IEM undergraduate program. There, students combine the knowledge acquired in the remaining CUs of the respective semester, working in teams to solve complex, real-life challenges.

Thus, the core objectives of the IPIEM courses, besides enhancing students' technical skills by applying theoretical knowledge, is the development of soft skills such as teamwork, communication, and problem-solving, which are essential in their future professional environments. The initiative aims to create an immersive learning experience where students engage in hands-on activities, critical thinking, and collaborative work, simulating the challenges faced in the industry.

2.1 Integrated Project in Industrial Engineering and Management I

As the first integrated project, IPIEM I is situated in the first semester of the first year and incorporates a range of Science, Technology, Engineering, and Mathematics (STEM) subjects. More precisely, students begin their courses with Computer Programming I (CP I), Introduction to Economics Engineering (IEE), and Introduction to Industrial Engineering and Management (IIEEM), all of which are offered by the Engineering School. Additionally, subjects from the Science School, such as Calculus for Engineering (CE) and Linear Algebra for 3 Engineering (LA), are also taught this semester. These CUs come together in an integrated project (IPIEM I), which holds five European Credit Transfer System (ECTS), totalling 140 hours of student work.

By default, this PBL project focuses on sustainability. For the current third-year students of the IEM undergraduate degree, the theme of their first IPIEM (2022/2023 academic year) was to design a production system to value end-of-life clothes. As such, 68 freshman students were organized into eight teams of seven to nine members. The project was also carried out by a team coordinator, instructors from various courses, volunteer tutors (including department lecturers and third-year IEM students), and occasionally, volunteer educational researchers, making up a total of 17 team members for this specific edition.

Throughout the project, the teams' assessments were conducted at specific milestones, which included some deliverables to be presented, as illustrated in Table 1.

Table 1. Milestones, deliverables, and weight of each in the assessment methodology of IPIEM I (adapted from Alves et al. (2023)).

Milestone	Date	Deliverables	Weight
1	2022.09.28 (Week 2)	Pilot-project presentation (10'/team + 5' discussion)	Not assessed
2	2022.10.26 (Week 6)	Team progress (10'/team) + enlarged tutorial (15'/team)	7.5% (team) + not assessed
3	2022.11.15 (Week 9)	IEM@ProjectNetworking result (5'/pair)	10% (individual)
4	2022.12.09 (Week 12)	Preliminary report (40 pages maximum)	20%+5% (team)
5	2023.01.11 (Week 14)	Final report (50 pages maximum) + Prototypes	35% + 20% (team)
6	2023.01.16 (Week 15)	Final presentation and discussion (15'/team + 30' discussion) + blog	12.5% + 5% (team)

During the first week of classes (from September 19 to 23), IPIEM I is introduced to the freshman students, who arrived at the university one week before. In this session, a learning project guide, which outlines all the details of the PBL organization process, is presented by the coordination team. The guide includes the expected learning outcomes for each course, schedules, the role of the tutors, contacts, and other essential information.

By then, they are ready to develop teamwork skills and use web communication tools, such as blogs, to support the development and exposure of their work and ideas. By the following week, they are expected to present their findings in the pilot-project presentation, which includes their study of the theme, their team organization, and how they plan to manage the blog.

Students are then required to begin drafting a report about their work. While each course defines its specific tasks and content, the goal is to integrate most of this content into the project. Additionally, students receive training in teamwork, focusing on team formation, the use of tools to enhance collaboration, project management, and communication platforms, such as Padlet, Blog, and Asana.

As part of their deliverables, student teams are required to review a report submitted by another team. This paper explores the critical thinking developed by the students performing the peer review, by examining the feedback provided, the questionnaire, the technical checklist, and the results of the report content.

To promote effective teamwork, each student is required to conduct anonymous peer assessments, after completing some milestones. These evaluations are then reviewed in meetings with team members, guided by tutors to help resolve any conflicts that may arise.

More details about the implementation of this project can be found in Alves et al. (2023).

2.2 Integrated Project in Industrial Engineering and Management II

As the previous integrated project, IPIEM II was first implemented in the academic year of 2021/2022, during the second semester of the second year of the IEM undergraduate degree. Four CUs participated in this PBL: Complements of Applied Statistics (5 ECTS), Operational Research and Optimization (5 ECTS), Numerical Methods (5 ECTS), and Information Systems and Technology (5 ECTS).

With the knowledge acquired in these curricular units, students were expected to solve an industrial engineering problem using real data, by applying statistical data analysis techniques, as well as incorporating tools for database manipulation and management and implementing software solutions related to data processing and analysis.

In the previous 2023/2024 academic year, the objective of the project was to define an efficient supply chain system for a product from an industrial sector in the northern region of Portugal (e.g., textiles, footwear, electronics, cork, etc.).

To achieve this, nine teams (randomly formed with eight members each from the 72 total students attending the CU) had to contact companies that meet these requirements so they could provide the necessary datasets about their supply chain. With this approach, the aim was to provide second-year students with a comprehensive and integrated understanding of the engineering topic and its practical applications in the real world (Carvalho et al., 2024).

As more advanced students, they are expected to develop more autonomous work, so they have fewer checkpoints, as outlined in Table 2, as well as not having a student mentor, unlike in the previous project.

Table 2. Milestones, deliverables, and weight of each in the assessment methodology of IPIEM II.

Milestone	Date	Deliverables	Weight
1	2023.02.28	Poster presentation session (pitch) (5' per team)	10% (team)
2	2024.04.12	Preliminary report (maximum 20 pages)	20% (team)
3	2024.05.27	Final report (maximum 40 pages)	40% (team)
4	2024.05.29	Final presentation (12'/team) and discussion of the work (maximum 15'/team)	30% (team)

In addition to the group assessment, the individual evaluation takes into account a correction factor calculated through the peer evaluations conducted after each milestone.

2.3 Integrated Project in Industrial Engineering and Management III

As the final IPIEM, this integrated project takes place in the second semester of the third and final year of the IEM undergraduate degree. Following the same principles as in previous editions, it involves 5 CUs, specifically Data Analytics (5 ECTS), Decision Models (5 ECTS), Logistics and Supply Chain Management (5 ECTS), Manufacturing Planning and Control (5 ECTS), and Project Analysis in Industrial and Engineering Management (5 ECTS). In the academic year of 2024/2025, the coordination team consisted of five teachers, one representing

each CU, and the students were divided into 10 teams, each consisting of 7 members, who were randomly assigned.

The objective is for students to be able to develop a team project based on a case study related to the increased demand for three products from a wood furniture manufacturing company. As a result, the company must increase its production capacity to meet the new orders promptly, while maintaining product quality and minimizing production costs. The overarching challenge for each student team is to develop proposals and plans across various areas, including equipment and labour requirements, logistics, production planning and control, and information systems, all aimed at helping the company achieve its objectives (Carvalho et al., 2024). In addition to the technical skills associated with the CUs, the aim is to also develop transversal skills (communication, teamwork, leadership, etc.). The evaluation method is described in Table 3.

In addition to the team assessment, there is an individual correction factor, determined by the peer evaluation before each presentation. The grade is also increased by 1 point if students attend all seminars conducted throughout the semester.

Table 3. Milestones, deliverables and weight of each in the assessment methodology of IPIEM III.

Milestone	Date	Deliverables	Weight
1	2025.03.18	Intermediate Presentation/Discussion	15% (team)
2	2025.05.20	Final Presentation/Discussion	15% (team)
3	2025.05.20	Final report	70% (team)

3 Methodology

The present study is based on the analysis of responses to a questionnaire on transferable skills applied to third-year students of the Industrial Engineering and Management bachelor's degree at the University of Minho. The survey was specifically targeted at students involved in the Integrated Projects in Industrial Engineering and Management I, II, and III, with the aim of understanding, on one hand, the skills effectively developed in the first two projects, and on the other hand, the students' expectations regarding the skills they hope to acquire with the completion of IPIEM III, which is scheduled to conclude in May 2025. The data collection instrument was structured to cover a set of transferable skills considered essential for the future professional performance of the students, such as oral and written communication, teamwork ability, and complex problem-solving, among others. Thus, the questionnaire included closed-ended questions using Likert scales as well as open-ended questions, allowing students to share additional comments about their experiences in the projects. The sample analyzed consists of 35 students, from a total population of about 70 enrolled in the third year of the degree, corresponding to a response rate of 50%. This rate is considered satisfactory for exploratory studies of this nature and provides a solid basis for analyzing general trends in students' perceptions. It is important to highlight that the responses were collected anonymously, ensuring the confidentiality of participants' personal data and encouraging greater honesty and spontaneity in the answers provided.

3.1 Profile of the respondents

The analysis of the respondents' demographic characteristics indicates a clear predominance of female participants, representing 74.29% (n=26) of the sample, whereas male participants account for 25.71% (n=9). Concerning age distribution, the majority of respondents are 20 years old (54.29%), followed by 21-year-olds (37.14%), with smaller proportions aged 22 (5.71%) and 24 years (2.86%). The age distribution observed among the participants aligns with the expected demographic profile of third-year students enrolled in the Industrial Engineering and Management program.

4 Results

Students' assessment regarding the degree of development of a set of transferable skills across the three projects was conducted using a 5-point Likert scale, where 1 corresponds to "Very poorly developed" and 5 to "Highly developed". The data analysis, presented in Table 4, was based on the percentage of students who assigned scores of 4 or 5, corresponding to the categories "Well developed" and "Highly developed", to the various transferable skills addressed in the IPIEM I, II, and III projects. This method of analysis allows for a more precise observation of the degree of positive perception regarding the development of each skill, using the frequency of higher scores within the sample of 35 students as a central indicator. In parallel, these perceptions were compared with the qualitative evaluation provided by instructors in a study by Carvalho et al. (2024), expressed through the scale: ++: developed; +: somewhat developed; -: poorly developed; --: not developed. This external perspective complements the quantitative analysis and provides additional insights into the students' educational progress.

Table 4. Transferable skills identified in each project: students' perspective versus faculty's perspective (adapted from Carvalho et al. (2024)).

Transferable Skills	IPIEM I		IPIEM II		IPIEM III	
	Students	Teachers	Students	Teachers	Students	Teachers
	Well developed/ Highly developed	Perception	Well developed/ Highly developed	Perception	Well developed/ Highly developed	Perception
Identification of critical points for the work	77.1%	-	85.7%	++	85.7%	+
Creativity expression	80%	++	80%	+	80%	--
Logical reasoning ability	91.4%	-	88.6%	+	91.4%	+
Persistence	71.4%	+	91.4%	-	91.4%	--
Adaptability	88.6%	-	88.6%	-	91.4%	-
Autonomous learning	82.9%	+	85.7%	+	88.6%	++
Willingness to help colleagues	88.6%	-	91.4%	-	94.3%	+
Proactivity	85.7%	-	88.6%	+	88.6%	+
Attendance	82.9%	--	88.6%	+	88.6%	--
Meeting deadlines	94.3%	+	94.3%	++	94.3%	+
Respect for differences	91.4%	--	91.4%	-	88.6%	++
Collaboration with the group	88.6%	++	82.9%	+	94.3%	+
Ethics and professionalism	91.4%	--	88.6%	+	94.3%	--
Collective construction of solutions	85.7%	-	82.9%	-	91.4%	-
Stimulating collaboration	85.7%	+	82.9%	-	91.4%	+
Recognition of colleagues' contributions	85.7%	++	88.6%	-	91.4%	++
Written communication	71.4%	+	80%	++	85.7%	++
Assertiveness	82.9%	++	85.7%	+	94.3%	++
Ability to listen and understand others	91.4%	+	91.4%	-	94.3%	-
Public speaking	80%	++	91.4%	++	91.4%	++
Conflict mediation within the group	77.1%	-	82.9%	-	82.9%	-
Learning based on recognizing one's own mistakes	88.6%	-	85.7%	+	85.7%	-
Openness to receiving criticism and feedback	85.7%	-	91.4%	+	91.4%	+

It's important to emphasize, however, that there is a fundamental distinction between the nature of the responses related to each project: while the evaluations for IPIEM I and II reflect students' retrospective perceptions of skills already developed, the responses regarding IPIEM III relate to students' expectations about the skills they hope to acquire. This distinction has implications for data interpretation, as a high rating for a skill in IPIEM III can reflect students' confidence or aspirations, rather than a confirmed outcome.

Overall, students demonstrate a strong appreciation for the development of transferable skills across the three projects. In several dimensions, the percentage of responses in the top categories exceeds 80%, indicating a broadly positive perception. Skills such as "Logical reasoning ability", "Meeting deadlines", and "Assertive communication" reach values between 91% and 94%, suggesting that students perceive that all integrated projects helped them develop these skills.

However, when compared with the evaluations provided by instructors, some discrepancies emerge that warrant attention, as certain skills are assessed more critically by teachers. For instance, "Adaptability" receives over 88% positive responses from students across all projects, yet it is consistently rated with a "-" by instructors. This may indicate a divergence in how this skill is perceived by the two groups. A similar situation is observed with the skill "Ethics and professionalism", which, despite receiving a high student rating (91.4%), is given the lowest possible rating ("--") in IPIEM III. This contrast may reflect a misalignment between students' expectations and instructors' perceptions of the challenges involved in developing this competence, particularly in the context of more complex or professionally oriented project environments.

In contrast, for the skill "Group collaboration", there is a clear convergence between students' perception (with over 85% of responses in the top categories) and the instructors' evaluation, which ranges from "+" to "++" in different projects. This alignment suggests that collaborative dynamics have been effectively encouraged and acknowledged by both sides.

"Creativity expression", while positively rated by students with percentages close to 80%, shows a declining trend in teacher evaluations over the course of the projects, dropping from "++" in IPIEM I to "--" in IPIEM III. This discrepancy may stem from differing perspectives: students, drawing on their experiences in the first two projects, may expect to continue developing creativity in IPIEM III; whereas instructors, based on their familiarity with the structure and demands of the third project, anticipate a reduced emphasis on creative expression due to its stronger focus on technical execution and task completion.

Other skills, such as "Meeting deadlines", are rated highly by both students and instructors. Interestingly, however, this competence still appears in the open-ended responses as an area for improvement, suggesting that positive quantitative ratings may not fully capture individual difficulties or varying experiences within the group.

These qualitative comments, which allowed students to freely identify the competencies they perceived as less developed during each of the project phases, are limited in number (three per project), but responses reveal consistent and recurring patterns throughout the academic journey, highlighting aspects that may be underrepresented or generalized in the quantitative analysis.

The most frequently mentioned competency was time management, identified as a recurring challenge in the first two project editions and anticipated as a potential difficulty in the third. This observation is particularly noteworthy given that, in the Likert-scale analysis, the competency of "Meeting deadlines" was among the highest rated by both students and instructors. This apparent contradiction may reflect a distinction between group performance and individual self-perception, suggesting that although teams were generally able to meet deadlines, many students acknowledged weaknesses in their personal ability to organize and plan their time.

Proactivity was also identified as an area for improvement at various stages of the project. The repeated mention of this skill at different moments in the academic path indicates a growing awareness among students of its importance, particularly its connection to initiative, responsibility, and autonomy within the context of teamwork. Although proactivity received reasonably positive percentages in the quantitative analysis, its absence among the top-rated competencies reinforces the significance of this qualitative evidence.

Another theme that emerged from the open-ended responses was the need for stronger alignment between the projects and the professional world. Students expressed a desire for a more direct connection with real business contexts, including the integration of practical challenges, case studies, or mentoring opportunities with industry professionals. This suggestion highlights the pedagogical value of realism in learning experiences and may be interpreted as a call for a partial reconfiguration of the projects to foster closer alignment with the demands and dynamics of the labour market.

5 Conclusions

The overall analysis of the collected data highlights the positive impact of the IPIEM on the development of transferable skills throughout the course. While students show optimism and confidence, particularly regarding the anticipated outcomes of IPIEM III, faculty feedback provides a grounded and sometimes more critical perspective. Recognizing the difference between experienced skill development in the earlier projects and expectations for the final project is essential for accurately understanding and acting upon these results. This nuanced view offers valuable guidance for enhancing future iterations of the program.

The discrepancy between students' self-perception and faculty assessment, especially in skills such as "Ethics and Professionalism" and "Adaptability," underscores the need to promote feedback moments throughout the entire educational process. Similarly, the qualitative contributions from students reinforce the need to develop skills such as time management and proactivity, which are frequently referred to as challenges, despite being well-rated quantitatively in the questionnaire.

In this context, the IPIEM projects stand out as key elements in the implementation of a PBL approach, providing realistic formative experiences focused on solving real-world problems and team collaboration. However, suggestions for a closer alignment with the professional world point to the potential for the evolution of this model, emphasizing the relevance of integrating business contexts and mentorship practices.

Thus, this research contributes to strengthening an approach of self-assessment and continuous improvement, serving as a valuable resource for the refinement of future pedagogical strategies. The continued data collection in the upcoming academic years will allow for monitoring the impact of integrated projects on the development of essential skills for entering the job market.

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The Role of Project-Based Learning in Developing Sustainable Fashion Solutions: Insights from the Eco-Design Challenge

Sofia Moreira¹, António Dinis Marques¹

¹ Centre for Textile Science and Technology (2C2T), Department of Textile Engineering, University of Minho, Guimarães, Portugal

Email: soracomo@gmail.com, adinis@det.uminho.pt

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Abstract

Project-Based Learning (PjBL) has gained widespread recognition as an effective approach for engaging students with real-world challenges, particularly in sustainability-related fields. By immersing students in hands-on projects, PjBL fosters collaboration, critical thinking, and creativity, enabling learners to apply theoretical knowledge to practical situations. This methodology enhances engagement while developing transferable professional skills, such as teamwork and communication, essential for career readiness. This study explores the application of PjBL within the Eco-Design Fashion Challenge (E-DFC), a project aimed at developing sustainable restaurant and bar uniforms for El Corte Inglés. Adapting the framework proposed by Krajcik and Blumenfeld (2006) and guidelines from the Buck Institute for Education (BIE), the initiative was structured into seven key elements of PjBL: "Contextualisation," which situated this challenge within its academic context; "Problematisation," introducing project regulations and the central question; "Situated Inquiry," encouraging students to explore various approaches and gain insight into El Corte Inglés' brand identity; "Design Development and Field Research," where students refined their designs, some focusing on sustainability strategies and others conducting field research on professional challenges; "Technological Tools," where students selected and applied relevant fashion design software and equipment; "Creation of Prototype," involving pattern making and sewing to produce the final uniform aligned with their inspiration, eco-design principles, and brand identity; and finally, "Results and Disclosure," which included project evaluation, the announcement of winners, prize distribution, and media dissemination. This process underscores the integration of sustainability into the design process, the use of technology to support learning, and the real-world application of fashion design principles. This exploratory case study highlights the potential of PjBL to cultivate critical thinking, creativity, and professional skills, equipping students to tackle the challenges of sustainable fashion design and contribute to a circular fashion industry.

Keywords: Fashion Design Education; Project-Based Learning; Circular Economy.

1 Introduction

Project-Based Learning (PjBL) is rooted in the educational theories of John Dewey, Jean Piaget, and Lev Vygotsky, who laid the psychological and pedagogical foundations for this approach. Dewey (1916) emphasised the importance of experiential learning and active student engagement in real-world problems. Piaget's constructivist theory (1952, 1970) reinforced the idea that knowledge is built through interaction with the environment, highlighting the role of experimentation and discovery in learning. Vygotsky (1978) introduced the concept of the zone of proximal development, underscoring the significance of social mediation and collaborative learning, both essential elements in PjBL.

These theoretical contributions shaped its core principles, including student-centred learning, knowledge construction through practice and reflection, and collaborative problem-solving. Over time, PjBL has evolved to incorporate 21st century skills such as communication, critical thinking, creativity, and collaboration – often referred to as the 4 C's (Bell, 2010; Larmer & Mergendoller, 2012). Unlike traditional teaching methods, which often prioritises content delivery, PjBL has proven to be more effective in promoting active learning, critical thinking, fostering autonomy, decision-making, and self-management (Markham et al., 2003; Bell, 2010; Gam & Banning, 2020; Lee, 2018; Lee et al., 2024).

The Buck Institute for Education (BIE) defines PjBL as a structured teaching method where students acquire knowledge and skills through extended inquiry into complex, real-world questions (Bytyqi, 2021). Instead of passively receiving information, students investigate topics, formulate the problem before developing their solution (Lima et al., 2024), and present their findings to an audience beyond the classroom, enhancing motivation and engagement (Larmer et al., 2017).

Building on these theoretical foundations, two established PjBL models were selected to structure the E-DFC: the framework proposed by Krajcik and Blumenfeld (2006), which is primarily oriented towards science education, and the guidelines developed by BIE (Larmer & Mergendoller, 2012; Larmer et al., 2015; Larmer et al., 2017), which offer a broader, interdisciplinary approach.

Krajcik and Blumenfeld (2006) define PjBL through five key elements. The first is the presence of a driving question, which defines the central problem of the project and guides the entire investigation. Secondly, students are challenged to engage in an active exploration process, where they investigate the problem within a real-world context, applying key concepts from the discipline as they progress. Collaboration is also fundamental, fostering interaction between students, teachers, and even community members, replicating the real-world challenges. Another distinguishing feature is the use of educational technology, which supports students in accomplishing tasks that might otherwise be beyond their current capabilities. Finally, PjBL culminates in the creation of tangible and shareable artefacts, allowing students to publicly showcase their learning.

With several points in common with this perspective, Larmer and Mergendoller (2012) outline eight essential components that ensure the effectiveness of PjBL: significant content, need to know, a driving question, student voice and choice, 21st-century skills, in-depth inquiry, critique and revision, and public audience. These elements structure the learning process, making it more engaging and meaningful. Teachers must design projects around key learning objectives, ensuring that students perceive the content as relevant to their academic and professional growth. Unlike traditional teaching methods that often focus on content coverage, PjBL encourages deeper understanding through active investigation and application, allowing students to internalise knowledge more effectively. A crucial factor in student engagement is the "need to know" — when students recognise the practical relevance of their learning, they become more motivated. Introducing a project with an engaging "entry event," such as a debate, a video, or a real-world scenario, helps spark curiosity and inquiry. The driving question provides a clear purpose and challenge, guiding students toward an open-ended, complex problem that requires critical thinking and exploration. Student autonomy is also a key aspect, with varying levels of freedom in choosing project themes and execution strategies. Developing 21st-century competencies is central to PjBL, ensuring that students acquire skills essential for academic and professional success. In-depth inquiry fosters problem-solving and innovation, while structured critique and revision processes help refine their work. Finally, public presentation enhances authenticity, reinforcing the importance of quality and real-world application.

Building on these perspectives, the E-DFC was structured as a collaborative initiative that reinforced the connection between education, industry, and sustainability. Organised by the University of Minho (UM) in partnership with El Corte Inglés – Grandes Armazéns, S.A., and ToBeGreen (a spin-off of the UM), the challenge took place during the 2023/2024 academic year and was designed for students in the bachelor's degree in Fashion Design and Marketing. With a strong emphasis on eco-design and circularity, participants were tasked with developing a restaurant and bar uniform for El Corte Inglés, incorporating materials sourced from a circular economy (CE), including recycled fabrics and dead stock provided by ToBeGreen. By integrating creative problem-solving with industry-driven sustainability goals, the challenge offered students a hands-on learning experience that bridged academic knowledge with professional practice, equipping them with skills to navigate

the evolving landscape of sustainable fashion. This exploratory study aims to contribute to the growing body of research on the impact of PjBL and its role in advancing sustainability in higher education, demonstrating how structured, industry-driven challenges can foster transformative learning experiences and prepare students to address real-world environmental challenges.

2 Eco-Design Fashion Challenge (E-DFC)

The E-DFC was built upon the framework developed by Krajcik and Blumenfeld (2006) and the guidelines established by the BIE (Larmer & Mergendoller, 2012; Larmer et al., 2015; Larmer et al., 2017). Both models emphasise student engagement, deep inquiry, collaboration, and real-world application. For this initiative, the structure was adapted to the specific context of the challenge and the field of fashion design, incorporating seven key elements (Figure 1) to ensure relevance and effectiveness.

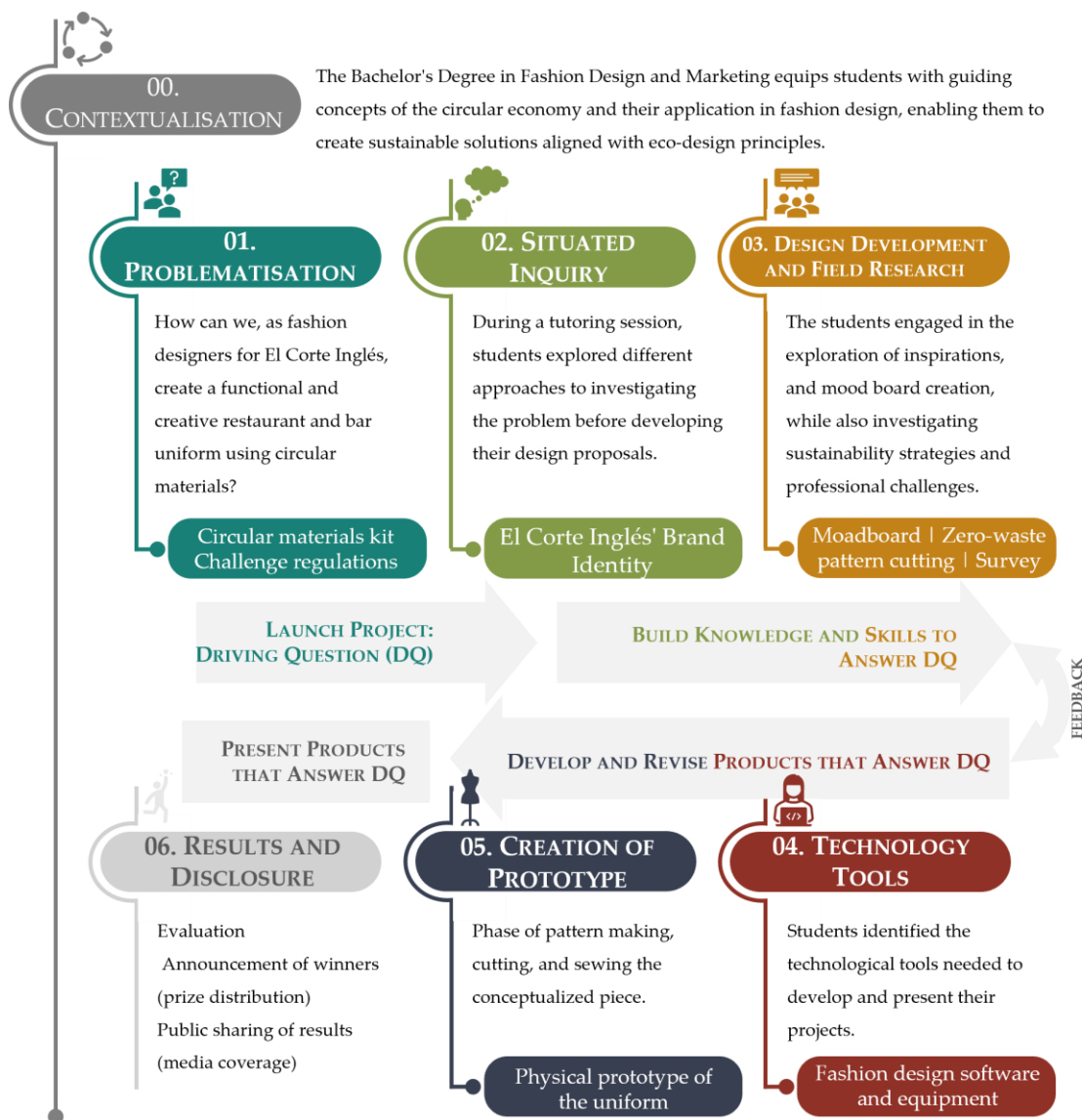


Figure 1. Phases of the E-DFC, a PjBL initiative (adapted from Krajcik and Blumenfeld, 2006; Larmer & Mergendoller, 2012; Larmer et al., 2015; Larmer et al., 2017).

00 Contextualisation

Given the participants' academic background, contextualisation was essential to position the E-DFC within their studies. The sample comprised 23 third-year students from the University of Minho's Bachelor's Degree in Fashion Design and Marketing, who took part in the initiative during the 2023/2024 academic year. This undergraduate programme integrates CE principles into fashion design, preparing students to develop sustainable and innovative solutions. These concepts are progressively introduced throughout the curriculum, with a more structured focus in the discipline "Comfort and Sustainability in Fashion", where the E-DFC was implemented.

Additionally, students in this programme are already familiar with project-based work, having engaged in "Fashion Design Project", an interdisciplinary discipline spanning every semester in the first two years and extending across the entire final year. This structure fosters a holistic approach to design challenges, strengthening their ability to integrate knowledge across disciplines and reinforcing their capacity to work within a project-oriented framework.

01 Problematisation

In the first session, students were introduced to the E-DFC through a presentation of the project regulations, outlining the fundamental guidelines for developing the uniform. The session also introduced the driving question that would guide the entire creative process: "How can we, as fashion designers for El Corte Inglés, create a functional and creative restaurant and bar uniform using circular materials?" Following BIE guidelines, this question was designed to be engaging, challenging, and open-ended, sparking interest by addressing a relevant and contemporary issue. Its complexity encouraged in-depth inquiry and critical thinking, requiring students to apply the essential concepts and skills defined as learning objectives. Aligned with the Design Challenge type of question, which is answered through the creation (and often execution) of a design that effectively meets specific requirements, its formulation followed a structured approach: "How can we, as (student role), create/research/develop (task) in order to (intended goal)?" (Lee, 2018).

This session also clarified assessment criteria, available materials, and competition requirements, ensuring students fully understood the scope and constraints of the challenge. Each student had to submit a comprehensive design proposal, with outcomes classified into four product categories (Larmer et al., 2017):

- Presentation product: A mood board illustrating conceptual inspirations, colour schemes, textures, and the design's contextual background.
- Written product: A brief descriptive statement outlining the design concept and sustainability features.
- Written product: Technical sheets with front and back sketches, specifying materials, accessories, and construction details.
- Constructed product: A physical uniform prototype incorporating ToBeGreen fabrics, allowing up to 10% additional materials for aesthetic or functional enhancements.
- Media product: Visual documentation (photographs / videos) effectively presenting the prototype.

02 Situated Inquiry

In the second phase, students engaged in an exploratory tutoring session focused on situated inquiry, critically examining different approaches to addressing the challenge. This stage encouraged deeper reflection on how to structure their projects, while the tutor played a key role in identifying knowledge gaps and guiding students toward areas requiring further exploration. As the inquiry progressed, it became evident that a comprehensive understanding of El Corte Inglés' history and brand identity was crucial to ensuring the uniform design aligned with the company's visual and conceptual identity. This connection to branding, design, and visual identity principles became an integral part of the project, shaping students' design decisions. Following a project-driven learning approach, students integrated their research in different ways (Figure 2).



Figure 2. Examples of different approaches to integrating brand research into the design process, compiled from students' portfolios.

03 Design Development and Field Research

At this stage, a new tutoring session allowed students to refine their proposals, building on insights from previous phases. The focus shifted to garment design, with students exploring visual references, creating mood boards, and contextualising the concepts behind their uniforms.

Some students identified zero-waste pattern cutting as a key strategy to reinforce eco-design principles, experimenting with ways to optimise material use, minimise waste, and enhance sustainability in their designs (Figure 3). Meanwhile, others sought a deeper understanding of the practical challenges faced by restaurant and bar staff. One student even conducted surveys with industry professionals to gather insights on how workwear impacts comfort, functionality, and performance in real workplace settings (Figure 3). These field research and experimentation processes were instrumental in shaping design decisions, ensuring that final proposals balanced aesthetic appeal with practical demands.



Figure 3. Visual documentation of zero-waste pattern exploration and analysis of professional needs, including survey insights, sourced from students' portfolios.

04 Technological Tools

In line with the challenge criteria, students selected and utilised technological tools essential for the project's execution, choosing software and equipment that best supported their design and development process. Their selections reflected knowledge acquired throughout their degree, demonstrating familiarity with industry-standard tools used in fashion design. Beyond digital resources, constructing the uniform prototypes required specialised sewing equipment, including straight-stitch and overlock machines, ensuring precision in stitching, finishing, and structural integrity.

The integration of both digital and physical tools not only facilitated the realisation of creative concepts but also reinforced a structured and professional approach to the final project presentation, enhancing students' technical and practical skills in sustainable fashion design.

05 Creation of Prototype

In this phase, students applied their patternmaking and sewing skills to construct the physical prototype of the uniform (Figure 4). Throughout the process, they ensured that the final design remained faithful to the original concept, integrating eco-design principles while aligning with the brand's identity. This stage was crucial, as it materialised the project, synthesising knowledge from previous phases and transforming creative ideas into a tangible, wearable outcome.



Figure 4. Student-created uniform prototypes.

06 Results and Disclosure

The final stage of the challenge focused on the evaluation and dissemination of results, marking its conclusion and acknowledging students' efforts. The evaluation was carried out by a jury composed of representatives from the University of Minho, El Corte Inglés, and ToBeGreen, based on a structured set of criteria with specific weightings: descriptive statement (5%), mood board (5%), technical sheets with sketches (5%), physical prototype (15%), photographs and other communication materials (5%), creativity and originality of the proposal (25%), incorporation of circular design and sustainability principles (15%), and innovation and potential for real-world application (25%). Each jury member assigned a score from 0 to 10 for each parameter, and the final classification was determined by the weighted sum of all components, ensuring a comprehensive and transparent assessment process.

Following the assessment, winners and honourable mentions were announced, with the most outstanding proposals publicly presented. The results were shared during an award ceremony, featured in the YouTube programme "Já em Movimento pela Sustentabilidade," and covered in various newspapers and magazines. The first-place winner received a monetary prize, while two students were awarded paid internships at ToBeGreen. The media coverage extended across both internal and external communication channels of the organising entities (Figure 5).



Figure 5. Media coverage highlights showcasing the dissemination of the E-DFC results across various platforms.

3 Discussion

In recent years, there has been increasing emphasis on integrating CE principles into education, particularly in fashion design (Moreira, et al., 2025). Given the industry's significant environmental impact, fashion is shifting from linear production models to sustainable and circular practices. Education is key to this transition, equipping future designers with the knowledge and skills to adopt sustainable approaches. Embedding CE principles into curricula enables educators to cultivate a new generation of designers capable of transforming the industry through innovative and responsible solutions. Research highlights the importance of developing creativity, critical thinking, and ethical responsibility to prepare designers for environmental challenges and industry transformation (Binde & Freimane, 2022; Sehnem et al., 2024; Moreira, et al., 2025; Moreira & Marques, 2025b).

PjBL has proven to be an effective method for engaging students with sustainability-related challenges. Studies show that PjBL facilitates the understanding and application of sustainability principles across different contexts (Jollands & Parthasarathy, 2013; McGibbon & Van Belle, 2015). By immersing learners in real-world scenarios, this approach fosters critical thinking, creativity, and problem-solving skills, encouraging students to apply their knowledge to complex, practice-based challenges (Williams et al., 2017; Gam & Banning, 2020). PjBL also promotes active learning, linking theory with hands-on experience for deeper knowledge retention. In sustainability education, it has been particularly effective in teaching zero-waste design and raising awareness of resource efficiency in the design process (Gam & Banning, 2020). By addressing the multifaceted nature of sustainability, PjBL helps students connect theoretical concepts to real-world decision-making (Jollands & Parthasarathy, 2013).

The E-DFC illustrates the effectiveness of PjBL in fostering sustainability-driven design thinking among fashion students. The challenge demonstrated how structured, industry-aligned projects can bridge theoretical knowledge with practical application, reinforcing key competencies in eco-design, CE, and professional practice. One of its core strengths was its alignment with PjBL principles, particularly active learning, inquiry-based exploration, and problem-solving. The seven-phase structure allowed students to progressively refine their projects, engaging in a real-world challenge that integrated branding, functionality, and sustainability concerns. At each stage, students applied critical thinking and decision-making, whether through situated inquiry, field research, or technological exploration, ultimately producing well-informed and technically refined prototypes.

The driving question played a crucial role in shaping the learning experience, prompting students to engage deeply with sustainability challenges in fashion. By designing a uniform that aligned with El Corte Inglés' brand

identity while incorporating circular materials, students encountered industry-relevant constraints, fostering a problem-solving mindset essential for professional practice. The design development phase revealed diverse approaches, with some students prioritising zero-waste pattern cutting, while others explored functional performance through engagement with industry professionals. This varied application of sustainability principles underscores the flexibility of PjBL, allowing students to tailor their learning pathways to personal interests and project needs.

Beyond technical skills, the E-DFC facilitated the development of soft skills essential for the 21st-century workforce, including critical thinking, creativity, autonomy, communication, and decision-making. The final stage, involving public presentations and media coverage, highlighted the importance of visibility in professional practice, enabling students to engage with a broader audience beyond academia. The internship opportunities at ToBeGreen further reinforced the challenge's industry relevance, offering students a direct entry point into the sustainable fashion sector.

Despite its strengths, some challenges emerged. The complexity of eco-design principles required intensive research and material experimentation, which was time-consuming within the constraints of the academic calendar. Additionally, while the collaborative nature of PjBL was evident, some students may have benefited from more structured guidance on integrating sustainability principles into technical decision-making. Future iterations of the E-DFC could incorporate additional workshops or mentorship with sustainability experts to further support knowledge application.

4 Conclusion

The E-DFC exemplifies how PjBL can be effectively integrated into fashion education to promote sustainable design thinking and industry preparedness. By engaging students in a structured yet flexible learning experience, the challenge bridged theoretical knowledge with hands-on application, fostering both technical and soft skills. The findings suggest that structured, industry-driven challenges play a crucial role in preparing students for the evolving demands of sustainable fashion, particularly by encouraging critical engagement with real-world constraints. Future studies could explore how PjBL initiatives in fashion education can further integrate emerging technologies and interdisciplinary collaboration, ensuring their continued relevance in an ever-changing industry.

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Development of a Visual Tool for Carbon Footprint Assessment within an International Collaboration for Sustainability Monitoring

Andressa Cristina da Silva¹, Cezer Vicente de Souza Filho¹, Isabela Oliveira Ferreira¹, Luciano Augusto Soto de Moura¹, Pedro Langendorf da Costa Vieira¹, Simone Borges Simão Monteiro¹, Iara Gomes Andrade¹

¹ Faculty of Technology. University of Brasilia. Brasilia, Brazil.

Email: andreluis.silva1015@gmail.com, cezersousa@gmail.com, isabela.oferreiraa@gmail.com, au.luciano@gmail.com, langendorf77@gmail.com, simoneborges@unb.com.br, 170012484@aluno.unb.br

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Abstract

The aim of this article is to create a visual tool for carbon footprint assessment, with the main goal of identifying and selecting crucial sustainability indicators. Carbon footprint monitoring is addressed at global and national scales. Through a structured process, the work proposes to correlate data from countries such as Brazil and Portugal, aiming to define and prioritize the most relevant indicators for tracking corporate carbon footprints. An initial literature review on global and national carbon footprint indicators was conducted. This paper will culminate in the development of an interactive dashboard, allowing for the visualization and calculation of companies' carbon footprints. Ultimately, the study seeks to offer an effective instrument to monitor and analyse the carbon footprint, supporting companies and environmental policies in their sustainability objectives and in the transition to a low-carbon economy.

Keywords: Greenhouse gases; Carbon footprint; ESG.

1 Introduction

The carbon footprint is defined as "the total set of greenhouse gas emissions caused directly and indirectly by an individual, event, organization or product, expressed as CO₂e." A GHG refers to any gas which accumulates in the atmosphere, absorbs and re-emits heat, thereby carrying the potential for global warming (SIAU, 2021). The carbon footprint includes both carbon emissions released during the combustion of fossil fuels and emissions of other gases, such as methane and nitrous oxide, which also contribute to global warming.

The scientific community, national governments, and global organizations widely agree that unpredictable short- and long-term impacts will arise due to climate change (IPCC, 2021). These impacts will have global effects, directly or indirectly. However, the countries most affected are not necessarily those responsible for producing the highest levels of greenhouse gas emissions or consuming the most non-renewable resources (Mendelsohn et al., 2006; Galli et al., 2014).

Due to growing global concern about environmental issues and the urgent need for sustainable development, governments, organizations, and the scientific community have been directing significant efforts toward achieving the Sustainable Development Goals (SDGs) and, consequently, reducing the carbon footprint in large organizations. These goals, established by the United Nations (UN), aim to promote sustainable economic growth, social inclusion, and environmental protection (United Nations, 2015). In the current context, the carbon footprint has emerged as a key indicator for assessing the impact of human activities on the global climate.

The central objective of this work is the development of a visual tool for carbon footprint measurement. This tool aims to identify and select key sustainability indicators, enabling the effective monitoring of organizations'

carbon footprints, both nationally and internationally. To achieve this purpose and define the most relevant indicators, the study outlines a plan that interlinks national and international approaches. The methodology involves literature review, scientific data collection, and the cross-referencing of information between countries like Brazil and Portugal to classify the main indicators. Understanding these elements is vital for the formulation of public policies and strategies adapted to different socioeconomic contexts (Tsuchiya et al., 2021). The expected outcome is for this tool to support organizations in monitoring their environmental performance, assist in defining emission reduction targets, and foster transparency in environmental management, aligning them with the SDGs and global sustainability targets.

2 Literature Review

This section presents an overview of recent literature and data related to CO₂ emissions, their impacts, and measurement methodologies. It also explores Brazil's emission profile, the alignment with Sustainable Development Goals (SDGs), and the main tools used to calculate the carbon footprint. The goal is to contextualize the development of sustainability indicators and highlight the relevance of carbon footprint assessment in global and national efforts for climate change mitigation.

2.1 Carbon Dioxide (CO₂) Emissions

According to Friedlingstein et al. (2023), atmospheric carbon dioxide (CO₂) concentrations have shown a continuous increase since 1960, rising from approximately 315 parts per million (ppm) to over 410 ppm by 2020. This steady growth, documented by institutions such as the Scripps Institution of Oceanography and NOAA/ESRL, directly reflects the impact of human activities, particularly the burning of fossil fuels and deforestation. In addition to the overall rise, the data also reveal seasonal variations, highlighting the sensitivity of the carbon cycle to natural and climatic dynamics.

This increase in CO₂ concentrations has significant implications for global warming and climate change. CO₂ is one of the main greenhouse gases, which traps heat in the atmosphere and contributes to rising global temperatures. These measurements reinforce the need for continuous monitoring and strategies to mitigate greenhouse gas emissions to limit future climate change impacts.

This global CO₂ emissions scenario also reflects the Brazilian context, where sectors such as energy, agriculture, and industry play significant roles in GHG emissions. Analyses from the Ministry of Science, Technology, and Innovation (MCTI) on emissions in Brazil show how these activities impact the atmosphere and highlight the country's specific challenges in pursuing sustainable solutions (Brasil, 2013).

According to Makiya and Fraisse (2014), Brazil's greenhouse gas emissions between 1990 and 2010 were largely driven by land use changes, particularly deforestation, which represented the largest share of total emissions throughout the period. Although emissions from the energy, agriculture and livestock, industrial processes, and waste treatment sectors remained relatively stable or grew gradually, emissions linked to forests and land use showed considerable fluctuation, with significant peaks in the mid-1990s and early 2000s, followed by a noticeable decline after 2004.

This analysis is essential for understanding Brazil's emission patterns and guiding public policies aimed at reducing greenhouse gases. Land use and forestry were the primary sources of GHG emissions in Brazil during the analysed period, followed by agriculture and, to a lesser extent, the energy and industrial sectors. The significant impact of land-use changes is mainly related to deforestation in the Amazon and other biomes. However, there has been a downward trend in emissions from this sector in recent years, reflecting efforts to combat deforestation.

On the other hand, sectors such as energy and agriculture have shown stable or increasing contributions, indicating the need for greater attention to these segments. This analysis reinforces the importance of integrated strategies that combine forest protection with advances in energy efficiency, sustainable agricultural practices, and waste management to reduce national emissions and meet international climate commitments.

2.2 Sustainable Development Goals (SDGs)

Figure 1 illustrates the main themes related to the SDGs, highlighting the distribution of international results obtained from the Web of Science database. Each rectangle represents a specific SDG, accompanied by a /number that indicates the quantity of studies, projects, or initiatives related to each goal. This analysis provides a comprehensive view of global efforts to promote sustainable development, emphasizing carbon footprint indicators and sustainable practices.



Figure 1. Main Themes Related to the SDGs (WoS, 2024).

The key findings focus on the following SDGs, which have a direct connection to the carbon footprint:

- SDG 9 - Industry, Innovation, and Infrastructure (110 results): This goal receives the most attention, emphasizing the importance of developing resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation. Industrialization and innovation play a crucial role in reducing the carbon footprint by adopting clean and efficient technologies.
- SDG 12 - Responsible Consumption and Production (88 results): This goal reflects the focus on sustainable consumption and production practices, which are essential for reducing environmental impact and promoting resource efficiency. The adoption of responsible practices significantly contributes to reducing greenhouse gas emissions.
- SDG 13 - Climate Action (75 results): The emphasis on this goal reinforces the commitment to mitigating climate impacts and tackling climate change. Initiatives focused on climate action are fundamental to reducing the global carbon footprint.

In addition to the highlighted topics, other important SDGs are included in the analysis, even though they are not the primary focus of this study. However, they remain relevant and deserve recognition. These goals emphasize the need for access to affordable, reliable, and sustainable energy, the promotion of decent work and inclusive economic growth, and the development of cities that ensure quality of life and environmental sustainability. They also highlight the conservation of biodiversity in terrestrial and marine ecosystems.

Although these goals are not the primary focus of this study, their inclusion in the analysis demonstrates their importance in the context of sustainable development and carbon footprint mitigation. The analysis indicates

that the main international initiatives and research efforts are focused on innovation, responsible consumption, climate action, and clean energy, reflecting the most urgent and critical themes for sustainable development and carbon footprint reduction.

2.3 Major Carbon Footprint Calculators

Carbon footprint calculators are essential tools for measuring the environmental impact of human activities, helping individuals and organizations understand and reduce their greenhouse gas (GHG) emissions. These tools use specific indicators to estimate the amount of carbon emitted directly or indirectly.

For a better analysis of Carbon Footprint indicators, it is essential to understand how these calculations are performed and the categories considered. Table 1 presents a selection of globally used calculators and the input categories for their measurements, based on a compilation originally made by Mulrow et al. (2019).

Table 1. Carbon Footprint Calculator Index by Input Category (Adapted from Mulrow et al., 2019).

Calculator	Home Energy	Transportation	Air Transportation	Food	Water / Wastewater	Extra Categories
Cool Climate Network	Electric, Gas, Oil, Other Fuels	Car, Bus, Train, Inter-City Rail	Short, Medium, Long, Extended	Yes	Water only (based on average)	Purchases (split by goods and services)
Henkel	Electric, Gas, Oil, Coal, Wood, Renewables	Car, Bus, Train, Motorbike, Bike, Walk	Based on km flown	Yes	Based on showers, baths, laundry, dishwasher	Sports, Holiday Travel and Accommodations
WWF	Electric, Gas, Propane, Oil	Car, Motorcycle, Bus, Train	Categories defined by distance from the UK	Yes	No	Miscellaneous
Terrapass	Electric, Gas, Oil, Propane, Gasoline, Diesel	Car, Electric Car, Boat, Train, Bus, Ferry, Taxi	Flight Information: fuel used, total miles, or trip length	No	No	No
IEEE Spectrum	Electric, Gas, Oil	Car	Short, Medium, Continental, Intercontinental	No	No	No
Cleanair Greener	Electric, Gas, Oil	Car	Based on miles flown	No	No	No

Mulrow et al. (2019) presents in their work a set of carbon footprint calculators, from which some examples were selected and adapted in Table 1, classified according to the level of detail (red for low, yellow for moderate and green for high). The categories evaluated include "Home Energy", "Transportation", "Air Transportation", "Food", "Water/Wastewater" and "Extra Categories". Tools such as *Cool Climate Network* and *Henkel* stand out for covering multiple dimensions of the carbon footprint, while others, such as *IEEE Spectrum* and *Cleanair Greener*, have a more restricted scope. This variety highlights the importance of selecting tools compatible with the purpose of the analysis. For example, individuals seeking to reduce their personal environmental impact may benefit from calculators that consider dietary habits and household energy use, while companies interested in reporting emissions or planning broader mitigation actions should prioritize tools that include categories such as corporate transportation, resource use and indirect emissions associated with production activities.

2.4 Project Context within Egalitarian

The Carbon Footprint Project is an initiative developed as part of the Egalitarian project portfolio starting in 2024. The Egalitarian Project is part of the Erasmus initiative, funded with European Union resources and is an

initiative aimed at engaging students from various countries to create sustainable solutions related to the Sustainable Development Goals (SDGs) (Egalitarian, 2025).

In Brazil, teams are primarily focused on solid waste management, where efforts are directed toward prevention, reduction, reuse, and recycling through waste picker cooperatives. However, there was no measurement of these results in terms of carbon dioxide emissions released into the atmosphere. This new approach enables the development of metrics and practical objectives related to the carbon footprint, which can be applied to other projects within the portfolio.

3 Methodology

According to Vergara (2006), applied research aims to solve real-world issues based on established theories. This study is classified as applied research, focusing on measuring the carbon footprint to help companies set carbon footprint reduction targets.

3.1 Research Classification

This is an exploratory study, according to Gil (2002), as it seeks to enhance familiarity with the topic and build hypotheses. The methodology combines systematic bibliographic and qualitative research. The literature review was conducted using the Scopus, Web of Science, and Google Scholar databases, considering contributions from Wackernagel and Rees (1996), pioneers in the ecological footprint concept. Recent approaches to integrating socioeconomic and environmental indicators were analysed.

Indicator selection was based on the criteria of Wiedmann and Minx (2008), prioritizing traceability and comparability. A multi-criteria analysis was applied to rank indicators according to sectoral and regional relevance. The data underwent statistical modelling to measure CO₂ emissions across production chains, following the guidelines of the Intergovernmental Panel on Climate Change (IPCC, 2019), identifying gaps and opportunities in emissions management.

3.2 Research Structure

The research structure highlights the key analyses and essential components that form the core of the study as a whole. This structure is visually represented in Figure 2. The study was designed based on a set of interconnected objectives and activities, focusing on identifying, prioritizing, and presenting key sustainability indicators, with an emphasis on the carbon footprint. Initially, a global analysis of indicators was conducted, exploring their applicability across different sectors and contexts. This phase included a detailed literature review and a critical analysis of existing indicators, serving as a foundation for the subsequent stages.

Next, a national-level investigation was carried out, focusing on the relevance and applicability of indicators in the local context. This process also began with a literature review and data analysis across various sectors, allowing for an understanding of how these indicators could be utilized in different scenarios.



Figure 2. Research Structure.

Following the identification of indicators, a feasibility and prioritization analysis was conducted based on criteria such as scope, ease of measurement, and impact on environmental policies. Finally, a dashboard was designed for visualizing indicators and calculating the carbon footprint. This included selecting an appropriate

platform, defining an intuitive layout, implementing an indicator-based calculator, and creating a user guide to ensure usability. The dashboards were validated with stakeholders and experts.

4 Results and Discussion

The results were organized into five subsections. The first details the criteria for selecting carbon footprint indicators; the second presents the key indicators; the third analyses their application in carbon footprint calculators; and the last two discuss the development of the dashboard, featuring standardized indicators validated by stakeholders.

4.1 Criteria for Selecting and Identifying Indicators

The measurement of carbon footprint is essential for mitigating environmental impacts, especially in the face of climate change. The SDGs provided guidance for prioritizing relevant, comparable, and sustainability-aligned indicators, such as carbon intensity of GDP and carbon footprint per capita (Gama-Rodrigues et al., 2022). In Brazil, tools like SEEG are crucial for high-impact sectors, such as agriculture and energy (SEEG, 2023).

The selection of indicators should consider scalability and comparability. While transport and energy are global sectors, in Brazil, agriculture and deforestation are the main sources of emissions (Cerri et al., 2017). Using standardized metrics, such as the GHG Protocol and IPCC guidelines, ensures the usefulness of the data (Gama-Rodrigues et al., 2022). Local adaptation is key, considering factors such as methane emissions in livestock and Amazon deforestation (SEEG, 2023). Table 2 presents the selection criteria for indicators, highlighting the most relevant metrics both globally and nationally.

Table 2. Criteria for Carbon Footprint Indicators. (Authors, 2024)

Criteria	Description	Application
Alignment with Objectives	Indicators should be aligned with global SDGs and national targets, such as the Paris Agreement.	Global: Carbon intensity of GDP. National: SEEG targets and carbon regulation.
Sectoral Relevance	Focus on sectors with the greatest environmental impact.	Global: Energy, transport, sustainable consumption. National: Agriculture, land use, energy.
Scalability	Indicators applicable at different levels (local, national, global).	Example: Territorial carbon footprint, export/import, per capita.
Comparability	Metrics that allow comparison between countries or regions.	Example: Indicators based on the GHG Protocol and IPCC guidelines.
Data Availability	Based on reliable sources, accessible, and regularly updated.	Global: Global Footprint Network. National: SEEG, national emissions inventories.
Feasibility of Data Collection	Easy data collection and processing at acceptable costs.	Data at acceptable costs. Indicators using data from public inventories or local estimates.
Regional Flexibility	Adaptable to local and sectoral contexts.	Example: Methane emissions in Brazilian agriculture, regional energy mix.

The strategic choice of carbon footprint indicators is crucial for accurately assessing environmental impacts. By aligning local efforts with global goals, it becomes possible to efficiently monitor GHG emissions and guide public policies and corporate strategies to maximize mitigation.

4.2 Performance Indicators

Key Performance Indicators (KPIs) measure whether the actions taken are meeting planned objectives. These indicators are listed in Table 3.

Table 3. Ranking of Indicators. (Authors, 2024)

Indicator	Objective	Calculation	Periodicity	Data Collection
Total Carbon Footprint	Measure the total environmental impact of human activities.	Sum of greenhouse gas (GHG) emissions (tCO ₂ e) from all direct and indirect sources over a given period.	Annual or per project	National inventories, sectoral reports, or data from companies and governmental organizations.
Per Capita Carbon Footprint	Assess the average emissions impact per individual in a region or country.	Division of the total carbon footprint by the number of inhabitants in the studied area.	Annual	Population data and national or regional inventories.
Carbon Intensity of GDP	Relate carbon efficiency to the economic activity of a country or region.	Division of total GHG emissions by the Gross Domestic Product (GDP) of the analyzed period.	Annual	Official economic reports and GHG emissions inventories.
Emissions by Economic Sector	Identify the most critical sectors in terms of emissions to prioritize mitigation efforts.	Calculation of total emissions for each sector (energy, agriculture, transport, etc.) based on sectoral data.	Annual	Sectoral reports, national inventories, and direct measurements from major emitters.
Emission Scopes (GHG)	Analyse in detail the direct and indirect emissions of organizations.	Classification into Scope 1 (direct), Scope 2 (purchased energy), and Scope 3 (value chain).	Periodic, as needed	Organizational data, such as energy consumption, logistics reports, and operational emissions inventories.
Carbon Footprint of Products and Services	Evaluate the environmental impact of products or services throughout their entire life cycle.	Life Cycle Assessment (LCA), considering everything from raw material extraction to final disposal.	According to the life cycle	Data provided by suppliers, operational reports, and environmental inventories.

Carbon footprint indicators vary in scope and applicability:

- Total Carbon Footprint provides a general overview of greenhouse gas emissions (GHG) in a region.
- Per Capita Carbon Footprint highlights average emissions per inhabitant, useful for country comparisons.
- GDP Carbon Intensity assesses carbon efficiency in relation to economic growth.
- Sectoral Analysis identifies critical areas such as energy and transportation for mitigation efforts.

Additionally, the GHG Protocol (2025) structures emissions into three scopes:

- Scope 1 - Direct emissions from controlled sources.
- Scope 2 - Indirect emissions from purchased energy.
- Scope 3 - Indirect emissions from the value chain.

Life Cycle Assessment (LCA) is widely used to calculate the carbon footprint of products and services, evaluating emissions across all stages of the production cycle, from raw material extraction to disposal. These indicators guide sustainable policies and strategies, promoting emission reduction and transforming global practices.

4.3 Dashboard

As the main database for the creation of the dashboard, data from two companies in Portugal were used, one from the construction sector (Company 1) and another from the textile sector (Company 2), both with their identities preserved. The provided data include the consumption of acquired energy for both companies, as well as water consumption and waste generation for the construction company. Data on emissions from the use of machinery powered by natural gas, electricity, and maritime transport were also considered.

The collected data were compiled into the interactive dashboard, developed in Power BI, providing a clear and dynamic visualization of the carbon emissions of both companies. It is possible to monitor and analyse environmental metrics in detail, such as energy consumption, water usage, waste generation, and emissions from different sources. Additionally, strategic insights can be generated, enabling more informed decision-making, promoting transparency, and enhancing efficiency in carbon footprint management.

Figures 3 and 4 present images of the developed dashboard.

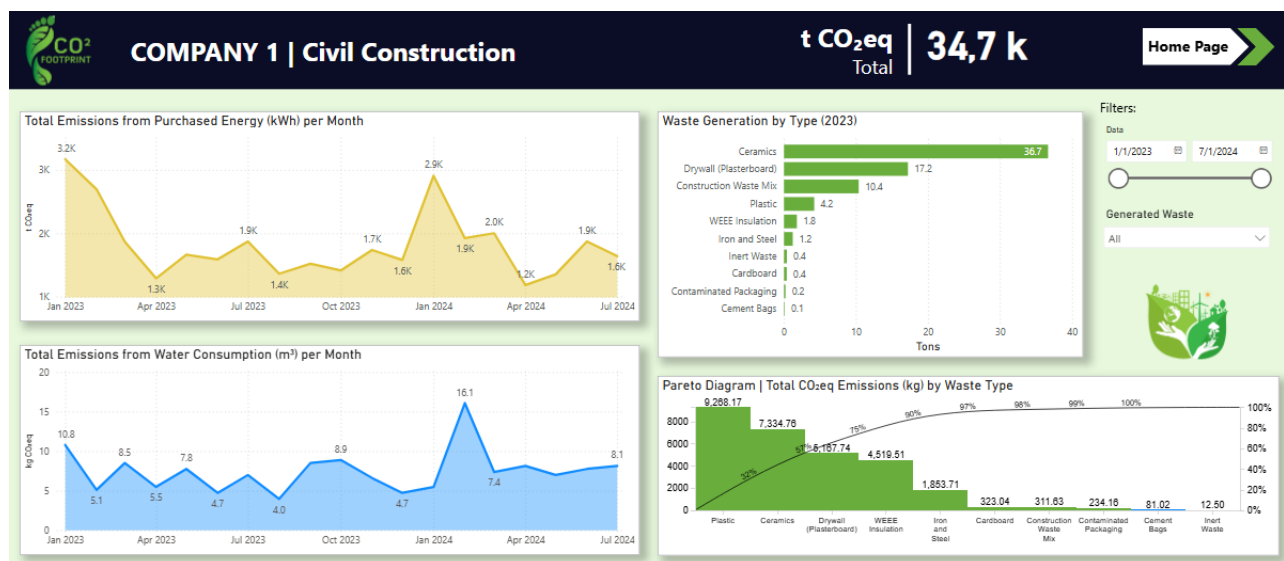


Figure 3. Dashboard of Company 1 (Civil Construction).

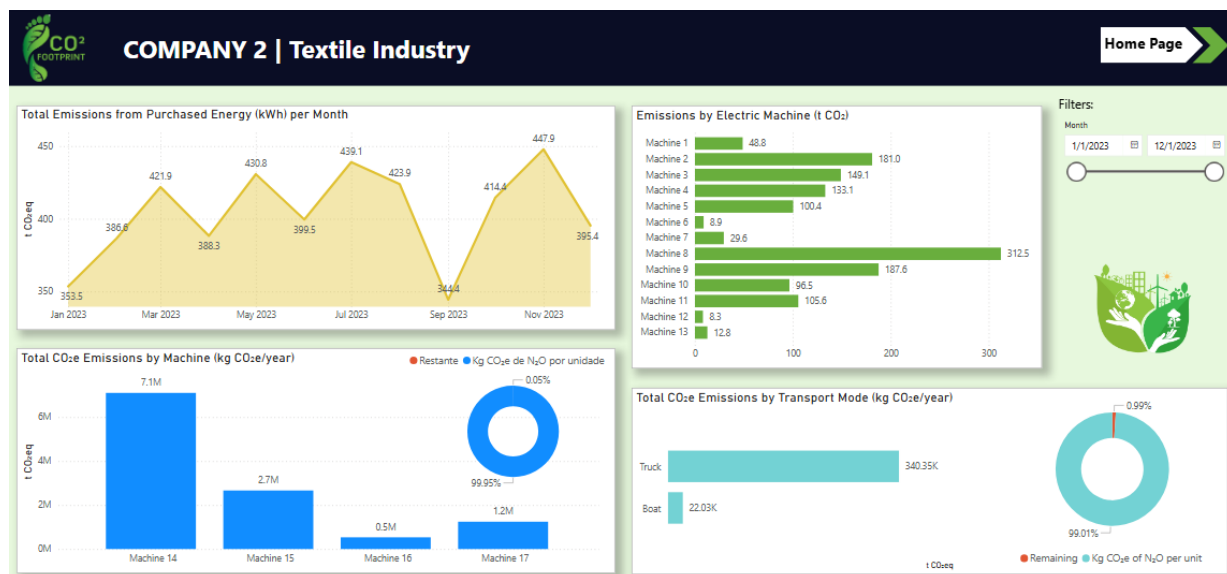


Figure 4. Dashboard of Company 2 (Textile Industry).

The combination of dashboards and carbon calculators strengthens companies' environmental management. While dashboards provide a clear and interactive view of the data, calculators help estimate greenhouse gas emissions based on different indicators. Together, these tools make it easier to monitor, simulate scenarios, and make more sustainable decisions, making carbon footprint management more efficient and transparent.

5 Conclusion

The Carbon Footprint Project has successfully established a robust methodology for identifying and prioritizing key carbon footprint indicators at both global and national levels, exemplified by the cross-referencing of data between Brazil and Portugal. This approach, informed by a thorough literature review and validated by stakeholders, has paved the way for the development of practical tools for monitoring and analysing carbon emissions. The project's focus on alignment with SDGs and global environmental policies ensures the relevance and applicability of the selected indicators for driving sustainability efforts.

The ongoing development of an interactive dashboard, demonstrated through the initial integration of data from Portuguese companies, signifies a tangible outcome of the project. This dashboard promises to be an effective tool for visualizing environmental metrics and calculating companies' carbon footprints, thereby supporting informed decision-making and promoting transparency. Ultimately, the Carbon Footprint Project contributes significantly to the broader goals of the Egalitarian initiative by providing a framework for measuring and managing environmental impact, aiding companies and policymakers in achieving their sustainability objectives and contributing to a global transition towards a lower-carbon economy.

The study successfully achieved its main objectives by identifying and prioritizing key carbon footprint indicators and developing a functional dashboard capable of visualizing and calculating emissions data. These tools support organizations in monitoring their environmental performance and aligning with international sustainability goals. However, the research faced some limitations, such as the restricted availability of standardized data from different sectors and regions, as well as operational inconsistencies in some online calculators during the testing phase. Future studies could expand the analysis by incorporating data from a broader range of industries and countries, as well as exploring the integration of real-time data collection systems and machine learning techniques to enhance predictive capabilities and automate sustainability reporting.

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A PBL Approach Design for Fostering Female Vocations in IT Engineering

Laura Camila Grimaldos-Velandia¹, Liliana Fernández-Samacá¹

¹ Universidad Pedagógica y Tecnológica de Colombia, Signal processing research group, Sogamoso, Colombia.

Email: laura.grimaldos@uptc.edu.co, liliana.fernandez@uptc.edu.co

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Abstract

The underrepresentation of women in Science, Technology, Engineering, and Mathematics (STEM) careers, is a global and national challenge. Although progress has been observed in the participation of women in STEM in Colombia, the relative gender gap, especially in Information Technologies (IT), remains significant and concerning. The department of Boyacá is not exempt from this reality, although the scarcity of specific data limits a detailed understanding of the local situation. This work addresses this issue by using student-centered approaches. It proposes the design of a Project-Based Learning (PBL) approach, mediated by a digital tool, aimed at female vocational high school students in Boyacá. The study seeks to identify some underlying causes for the low choice of IT careers among this specific group and in this context, to design, develop, and evaluate a contextualized educational intervention. A mixed-methodology approach will be employed, integrating qualitative and quantitative methods to explore causes and utilizing Design-Based Research (DBR) to design, construct, and evaluate the proposed approach. This research is expected to provide a validated intervention model and a deeper understanding of the factors influencing young women's educational and professional trajectories in a local context, thus contributing to efforts for gender equity in the technological field.

Keywords: Gender Gap; IT Engineering Education; Project-Based Learning

1 Introduction

The participation of women in the fields of Science, Technology, Engineering, and Mathematics (STEM) has been a subject of global study. International data show that women represent approximately one-third of the research community (UNESCO, 2021) and close to 35% of students enrolled in higher education in STEM areas (UN Women, 2022; UNESCO, 2017). These differences in representation have historical backgrounds related to women's participation in scientific and academic institutions (Tonn, 2020).

In Colombia, data analysis between 2001 and 2021 indicates an increase in the absolute number of women graduating from STEM programs. However, their proportional representation relative to men has remained around an average of 37.9% during that period (Laboratorio de Economía de la Educación [LEE], 2023). Disaggregating by STEM areas¹⁰, the data for 2021 show significant variations: while women constitute the majority in the Sciences (56.3%), their participation decreases in Engineering (37.8%), Mathematics (34%), and finally Technology, where they represented only 20.3% of graduates. This field not only presents the lowest female participation but is also the only STEM area where the gender gap has widened over the last two decades (LEE, 2023). Both globally and in Colombia, female participation in Technology tends to be lower than the overall STEM average. The data point of 20.3% participation in Technology in Colombia is the lowest among the STEM areas analyzed in the LEE report and, according to the same report, represents a gap that has

¹⁰ The STEM categories, as defined in the source report are grouped as follows: **Sciences:** biology, physics, astronomy, geology, chemistry, and related fields (excluding health sciences). **Technology:** systems and computer engineering, software engineering, information and communication technologies engineering, informatics engineering, information systems management, and related fields. **Engineering:** engineering programs not included in the technology category, such as electrical, environmental, industrial, and civil engineering, among others. **Mathematics:** professional training programs in mathematics and statistics.

widened. This observation motivates a research focus centered on Engineering related to Information Technologies (IT).

This study focuses on the department of Boyacá, Colombia. Although the relevance of the topic at the regional level is recognized, there is limited availability of specific and disaggregated gender data on female participation in STEM and Technology within this context. This lack of detailed information hinders a deep understanding of the local situation. Nevertheless, Boyacá has implemented initiatives promoting digital inclusion and equity, such as the "Ella hace historia" program –in English, this expression could be translated as 'She makes history'– (Gobernación de Boyacá, 2021), business alliances for gender equity (Holcim Colombia, 2021), and investment in infrastructure like STEM laboratories (Secretaría de Educación de Boyacá, 2022). This panorama suggests a potentially receptive environment for focused interventions, but one that requires contextualized research to guide their design.

The reasons for investigating this topic are multifaceted. These align with principles of social justice and gender equity, as promoted by the UN Sustainable Development Goal 5 (Naciones Unidas, n.d.). Historical disparities in high-level scientific recognition (Nobel Prize Outreach AB, 2024) can also be interpreted as a reflection of systemic inequities that need to be addressed. From an economic and social perspective, it is argued that greater diversity in Technology could foster innovation. Furthermore, data for Colombia suggest that careers in engineering and technology tend to offer higher salaries and better employability rates compared to other fields (Navarro, 2022). Therefore, increased female participation in IT could contribute to reducing the overall gender pay gap (Departamento Administrativo Nacional de Estadística [DANE], 2020). Additionally, with a projected deficit of engineers in the country (Navarro, 2022), fostering female talent becomes a dimension of national need. Finally, this research relates to national Science, Technology, and Innovation policies (Mission-Oriented Policy - POM), particularly the missions "Knowledge and innovation for equity" and "Educating with Quality". Estimates such as those from the World Economic Forum on the time needed to close the gender gap in Latin America (World Economic Forum [WEF], 2022) suggest the relevance of investigating and implementing focused interventions.

Given this situation, the main objective of the present work is to design, develop, and evaluate an educational strategy to explore factors related to the choice of IT Engineering careers and foster female vocational education for K-9 to K-11 students, through an open extracurricular intervention.

2 Associated Factors in STEM Career Choices: A Literature Review

The literature suggests that female representation in some fields may be influenced by a complex network of interrelated factors operating at different levels (Amozurrutia, 2012). Therefore, adopting a perspective that integrates sociocultural, psychological, and systemic dimensions is considered a relevant approach.

2.1 Sociocultural Factors

Studies indicate that from an early age, young women may be exposed to gender stereotypes that associate STEM careers, especially technological ones, with male domains (Catucci, n.d.; Louten, 2022). These stereotypes can be influenced by historical narratives (Tonn, 2020), media representations, and differentiated social expectations (Sociology Institute, 2022). PISA report data suggest that, at age 15, boys show a greater propensity to aspire to careers in science or engineering compared to girls, despite girls, in some cases, achieving better results in logic and mathematics tests (OECD, 2015).

2.2 Psychological Factors

The literature suggests a connection between sociocultural and psychological factors. Exposure to stereotypes could influence young women's self-efficacy and confidence in their abilities in STEM areas, even when their academic performance is comparable to that of their male peers (OECD, 2015). In academic and professional environments with a male predominance, some women might experience a lower sense of belonging, a factor that has been correlated with academic success and persistence (Beach et al., 2024). Self-Determination Theory (SDT) highlights the importance of satisfying the psychological needs for autonomy, competence, and relatedness to foster intrinsic motivation (Ryan & Deci, 2000), which is relevant for perseverance in fields like STEM. The perception of engineering as a field focused on "objects" rather than "people" has also been proposed as a possible deterrent for young women with a stronger social orientation (Baron-Cohen, 2009).

2.3 Systemic and Internalized Factors

Biases can also be present in automated systems, as illustrated by the case of Amazon's AI-based recruiting tool, which showed biases against female candidates due to the historical data used for its training (Dastin, 2018). This underlines the importance of considering ethical and inclusion aspects in the development of digital tools. Additionally, some studies explore the concept of internalized sexism, where individuals may adopt or perpetuate discriminatory attitudes (Association for Women in Science [AWIS], 2024; Schwabe, 2024).

These different types of factors appear to interact. Social stereotypes (Catucci, n.d.) could be related to psychological barriers such as a lack of confidence (OECD, 2015) or belonging (Beach et al., 2024). These barriers could be affected by biased systems (Dastin, 2018) or environments perceived as hostile, and over time, could be internalized (AWIS, 2024; Schwabe, 2024). Therefore, an intervention could benefit from considering these interconnections.

3 Research Approach

This study is guided by the following research questions:

RQ1: What are the factors associated with the choice of IT Engineering programs by female vocational high school students in Boyacá?

RQ2: How could digital tools be used to encourage female participation in IT Engineering programs?

RQ3: How can a project-based learning approach mediated by digital tools, oriented towards gender equity in the choice of IT Engineering programs in Boyacá, be designed?

To answer these questions, the project's overall objective is: To design a project-based learning approach mediated by digital tools as an instrument to promote gender equity in the choice of IT Engineering programs in Boyacá. This is broken down into three specific objectives:

Goal 1: To identify factors associated with female underrepresentation in IT Engineering programs that can be addressed from a project-based learning approach.

Goal 2: To design a project-based learning approach adapted to the identified scenario.

Goal 3: To evaluate the impact of the proposed PBL approach.

To achieve these objectives, the methodological framework chosen is Design-Based Research (DBR). This methodology is considered suitable due to its focus on solving educational problems in real contexts through iterative cycles of design, implementation, analysis, and redesign. DBR seeks to develop practical solutions (in this case, a digital PBL intervention) and simultaneously generate theoretical knowledge about the learning

principles that influence the intervention's effectiveness. As an educational approach, this research explores Project-Based Learning (PBL) as the core strategy, mediated by digital tools.

The execution of the DBR methodology will align with the specific objectives through the following phases:

- **Phases 1 and 2 (Problem Identification and Investigation - Corresponds to Goal 1):** This includes a literature review, characterization of the target population, and qualitative fieldwork (e.g., interviews, focus groups) to identify and categorize contextual factors and barriers in Boyacá, and those addressable through the PBL intervention will be selected.
- **Phases 3, 4, and 5 (Solution Development and Prototype Construction - Corresponds to Goal 2):** In this phase, the PBL pedagogical strategy will be defined, and a prototype of the mediating digital tool will be constructed.
- **Phase 6 (Application and Evaluation - Corresponds to Goal 3):** A pilot course will be carried out using the designed strategies and tools. The impact will be evaluated using a protocol that incorporates both quantitative and qualitative instruments to measure variables such as interest in IT, perceived self-efficacy, and attitudes.
- **Phase 7 (Redesign - Continuous Refinement):** The findings from the evaluation will inform adjustments to the approach, following the iterative nature of DBR.

The research starts with the assumption that the factors influencing Technology Careers choice vary by context, and that a subset of these factors (related to perceptions, self-efficacy, etc.) can be positively influenced by a digitally mediated PBL approach adapted to the local context.

4 Proposed Intervention and Expected Contributions

The central intervention of this research is the design and evaluation of a Project-Based Learning (PBL) approach mediated by digital tools. PBL is selected for its potential to increase motivation and interest by connecting learning with real-world problems (Archer, 2024). Special attention will be given to incorporating findings about local factors (as per Goal 1) and applying ethical principles to avoid biases, considering historical cases like the one documented by Dastin (2018). The approach will be directed at addressing the identified intervenable factors. For example, if stereotypes or a lack of role models emerge as barriers, the projects could be designed to showcase women in technology and highlight collaborative and social impact aspects.

Contributions are expected in several areas:

- **Theoretical:** Contributing to the contextualized understanding of the factors influencing career decisions in a local context, and to the literature on DBR and digitally mediated PBL with a gender equity focus.
- **Practical:** Generating an evidence-based and contextually adapted PBL intervention model, potentially useful for educational institutions in similar contexts, such as Sogamoso City and its surrounding area. This also includes providing a practical tool for educators and contributing more broadly to national (POM) and international (SDG 5) objectives.

This proposal seeks to integrate DBR and PBL in an iterative and adaptive manner, using active learning and employing technology strategically and ethically. This serves as an alternative to previous approaches that have sometimes been described in the literature as sporadic or decontextualized (Sociology Institute, 2022; OECD, 2015).

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PAEE/ALE'2025 Workshops and Hands-on sessions

Submissions accepted for the PAEE/ALE'2025 hands-on sessions.

Workshop - Learning programming with Generative AI: Hands-On Exploration and Ethical Reflection

Montse Farreras¹

¹ Universitat Politècnica de Catalunya UPC-Barcelona Tech, Barcelona, Spain.

Email: montserrat.farreras@upc.edu

DOI: <https://doi.org/10.5281/zenodo.15918309>

Abstract

What if every student had a tireless, patient coding tutor? Generative Artificial Intelligence (GenAI) makes this possible—but at what cost? GenAI has rapidly evolved into a versatile tool for tasks ranging from creative writing to problem-solving, with programming being one of its most transformative applications. These models offer not only solutions and inspiration but also instant, iterative feedback—making them powerful allies for skill acquisition. In this workshop, participants (with or without prior programming experience) will actively engage with GenAI to Experience AI-assisted programming first-hand; discuss techno-ethical implications (e.g., over-reliance, plagiarism, bias) and explore strategies to integrate these tools effectively into education while preserving deep learning.

Keywords: Active Learning; Engineering Education; Generative AI. Computing Methodologies

1 Introduction

Generative AI (GenAI) refers to a class of artificial intelligence models capable of producing text, code, images, and other forms of media in response to user prompts. Tools like OpenAI's ChatGPT¹¹, Google's Gemini¹², DeepSeek¹³ and GitHub Copilot¹⁴ are trained on extensive datasets and are able to generate highly coherent, human-like outputs. These capabilities make GenAI valuable for a wide range of tasks, including content creation, problem-solving, and decision-making. By enabling users to quickly draft documents, improve written work, and access information effortlessly, these tools are reshaping productivity and how we work and learn.

In educational settings, GenAI functions as an endlessly patient and always-available tutor. It delivers explanations adapted to individual learners' levels, assists in brainstorming, and offers real-time feedback—supporting a highly personalized and self-directed learning experience. Therefore, in recent years, artificial intelligence (AI) has attracted increasing interest within the education sector, as more institutions and organizations explore the potential of AI-driven technologies to enhance learning (Dwivedi et al., 2021; Su & Yang, (2023); Noroozi et al. (2024)).

In engineering education, students have quickly embraced GenAI tools, especially those geared toward programming (Becker (2023)). A growing ecosystem of platforms provides features like code generation, debugging assistance, and natural language explanations of technical concepts. These tools are transforming how students engage with programming, often surpassing traditional methods that rely on static documentation, textbooks, or delayed instructor feedback (Yilmaz et al. (2023)).

¹¹ chat.openai.com

¹² gemini.google.com

¹³ <https://chat.deepseek.com/>

¹⁴ <https://github.com/features/copilot>

The research community views GenAI as a significant and emerging opportunity in education (Alasadi & Baiz (2023)). However, ChatGPT, a cutting-edge natural language processing (NLP) model developed by OpenAI in 2019 (Lund & Wang, (2023)) was only released in late 2022. We are still in the early stages of understanding how to effectively integrate them into academic settings. Questions remain around when, how, and to what extent these tools should be incorporated into coursework and curricula and research around the topic has grown exponentially in the last years (Qadir (2023); Giannakos et al. (2024)). Moreover, while AI can greatly enhance productivity, it also brings challenges—such as the risk of hallucinations (incorrect outputs), over-reliance, frustration when used uncritically, and even the potential to replace meaningful learning rather than support it (Mittal et al. (2024); Sharples (2023)).

These uncertainties and challenges are the motivation for this workshop, which aims to explore these issues and foster thoughtful reflection on how GenAI can be integrated into the classroom in a way that enhances—rather than replaces—the learning experience.

In this workshop, participants will actively engage with GenAI tools—such as ChatGPT, GitHub Copilot, and cloud-based Python environments—to support their learning of Python programming. They will experience AI-assisted programming firsthand through activities like code generation, debugging, and project ideation. After exploring both the potential and limitations of these tools, we will open the floor for discussion. Debate will be focused on: (i) critical reflections on concerns and techno-ethical implications, such as over-reliance on AI, plagiarism, and algorithmic bias; and (ii) strategies for meaningfully integrating these tools into educational contexts to enrich and enhance student learning. This workshop paper mainly targets the Conference theme of Artificial Intelligence and digital technologies, its ethical implications are also considered.

2 Activities

In this hands-on session, participants will take part in an AI-assisted programming workshop, followed by a group reflection and an open debate on ethical considerations and best practices. Working in teams, participants will need one laptop per group. The session is designed to provide practical experience with GenAI tools while fostering thoughtful discussion on their use in education. The session is structured as follows:

- **Introduction:** We'll begin with a quick interactive poll: "Have you used AI for coding before?" Followed by a brief overview of GenAI tools with a focus on programming.
- **Team-based AI-assisted coding experience:** Participants will work in teams using AI assistants (e.g., ChatGPT, GitHub Copilot) and no-setup, cloud-based IDEs (e.g., Replit15, Google Colab). Each team will tackle a set of challenges:
 - Code Understanding: Analyze a provided Python program with the help of AI.
 - Code Generation: Prompt the AI to write a basic program (e.g., reversing a string), then adapt or expand it.
 - Debugging: Introduce errors into working code and use AI to identify and fix them.
 - Mini-Project: Collaborate with AI to build a small custom project (e.g., a to-do list app).
- **Group Reflections & Presentations:** Each team will share their project and first impressions of the experience. Sample questions: "What surprised you the most?" "Was the AI easy to use?" "Where did you find limitations?"

¹⁵ replit.com

- **Ethical Considerations & Best Practices (Open Debate):** We'll explore the challenges of using AI in learning environments. Debate will be aimed at identifying potential risks—such as blind reliance on AI, reduced problem-solving effort, or plagiarism—and propose best practices. For example: Verify AI suggestions with official documentation, use AI as a brainstorming partner, not a final answer key, reinforce fundamentals through manual coding practice.

Inspirational Questions to Spark Debate:

- Should AI-generated code be allowed in coding exams?
- How can educators integrate AI tools without diminishing learning outcomes?
- How should learning outcomes change when introducing AI tools?
- Does AI encourage creativity or discourage original thinking?
- What skills become more important in an AI-assisted world?
- Can AI help level the playing field for students with different motivations or backgrounds?
- Should students be taught how to “talk to AI” effectively?

3 Expected results

Through hands-on activities and guided discussion, participants will leave with:

- A practical understanding of GenAI's capabilities and limitations in the context of programming.
- Actionable strategies for using AI to enhance—rather than replace—the learning process.
- A critical perspective on the societal and pedagogical implications of GenAI in education.

4 Instructions for Participants

This activity is open to anyone with an interest in the topic. No prior experience with programming or AI tools is required to participate in the workshop. Participants are required to bring a laptop, otherwise a computer per team should be made available to ensure everyone can fully engage in the session.

5 Conclusions and Take-aways

Generative AI is reshaping programming education by providing instant support, personalized feedback, and creative inspiration. However, its effectiveness depends on mindful usage—balancing AI assistance with active problem-solving. Participants will leave with:

- Hands-on experience using AI for coding tasks.
- Frameworks for responsible use in educational settings.
- Awareness of ethical and pedagogical challenges.
- Strategies to integrate AI as a learning enhancer, not a crutch.

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Workshop - Unlocking Potential: Strategies for Motivating and Engaging Shy, Quiet, Introverted Students in Engineering Education

Valquíria Villas-Boas¹

¹ Federal University of Rio Grande do Sul, Campus Litoral Norte, Tramandaí, RS, Brazil

Email: vvillasboas@gmail.com

DOI: <https://doi.org/10.5281/zenodo.15918439>

Abstract

Motivating and engaging shy, quiet, introverted students in engineering education requires a thoughtful, inclusive approach that fosters confidence and active participation. These students often prefer reflection over spontaneous speaking, making it crucial to provide diverse engagement opportunities. This workshop aims to equip engineering faculty and people interested in engineering student engagement with practical strategies to foster motivation, confidence, and engagement among shy, quiet, introverted students in engineering programs. By understanding their unique learning needs, instructors can create inclusive learning environments that encourage active participation and academic success. In this workshop, we intend to introduce some studies and active learning strategies available to motivate and engage shy, quiet, introverted engineering students. More important than that, we intend to discuss with participants how to create a safe and supportive environment for engineering students who are shy, quiet, or introverted; how to offer alternative participation strategies; which active learning strategies participants already use to motivate and engage their shy, quiet, introverted engineering students; how technology can help motivate and engage engineering students. This workshop has as its main objective to empower educators to unlock the full potential of all engineering students, regardless of their level of extroversion, shyness or quietness, ensuring a more inclusive and effective learning experience.

Keywords: Engagement; Motivation; Shyness; Quietness; Active Learning; Engineering Education.

1 Introduction

In the landscape of higher education, especially within demanding and collaborative fields like engineering, student engagement and motivation are widely recognized as essential components of academic success (Chen, Lattuca, & Hamilton, 2008; Zepke, & Leach, 2010; Groccia, 2018; Kunicina, Caiko, & Grants, 2023). Active learning approaches—ranging from group problem-solving to peer instruction and project-based learning—have become cornerstones of modern engineering pedagogy due to their proven benefits in enhancing comprehension, retention, and critical thinking (Smith, Sheppard, Johnson, & Johnson, 2005; Jiménez, & Andersson, 2012; Fernandes, Mesquita, Flores, & Lima, 2014; Aji, & Khan, 2019; Prince, Felder, & Brent, 2020; Munna, & Kalam, 2021; Gamarra, Dominguez, Velazquez, & Páez, 2022).

However, such approaches often come with the implicit expectation of visible, vocal participation. This presents a challenge for a specific and often overlooked population: shy, quiet and/or introverted students. These learners, who may be highly reflective, intellectually capable, and intrinsically motivated, often struggle to thrive in environments that prioritize extroversion and verbal assertiveness (Medaille, & Usinger, 2020). Their internal engagement can be mistakenly perceived as detachment or lack of interest, especially when engagement is measured primarily by classroom participation or leadership in group settings.

There are many theories about motivation and engagement, but discussing these theories is not the purpose of this workshop. The main objective of this workshop is to discuss Active Learning through an inclusive lens as it pertains to shy, overly quiet and/or introverted students. Active learning is defined by student-centered, participatory approaches that emphasize doing and thinking over passive reception. While powerful, many

active learning strategies — such as think-pair-share, peer instruction, jigsaw, case studies, among others — can become barriers if they are not intentionally designed to accommodate different personality types. The goal, therefore, is not to abandon active learning, but to diversify the strategies so that shy, quiet, and/or introverted students are not excluded or penalized. Inclusive active learning recognizes that participation can take many forms, and that engagement need not always be vocal or immediate.

2 Activities

This workshop aims to equip engineering educators with practical strategies to foster motivation, confidence, and engagement among shy, quiet, introverted students in engineering programs. By sharing our experiences, we will collect ideas that will help create inclusive learning environments that encourage shy, quiet students' active participation and academic success. The activities in this workshop are:

- (i) Brief discussion on the importance of student engagement and motivation in engineering education.
- (ii) In small teams, participants will discuss which active learning strategies they already use to motivate and engage their shy, quiet, introverted engineering students.
- (iii) In the large group, participants will share the strategies discussed/listed in the small teams. If necessary, the workshop leader will add/complement the list with other strategies.
- (iv) In small teams, participants will be invited to plan a short, safe and supportive active learning segment of a class for shy, quiet, introverted engineering students using one or two of the strategies listed. This planning will be recorded in kraft paper and displayed in the walls of the room where the workshop will be held. Participants will present their plannings.
- (v) Reflecting on the results presented by the small teams.
- (vi) Final remarks.

3 Material needed for the workshop

There is no need for any special materials for this workshop.

4 Expected results

Engineering professors can benefit from a reflexive discussion about the difference between an introverted student, a shy student and a quiet student, and how we can plan interesting active learning classes where these students can participate actively. By the end of this workshop, we expect that the participants will have:

- increased awareness of engagement challenges for shy, quiet, introverted engineering students.
- a bigger menu of active learning strategies and practical tools for fostering shy, quiet, introverted engineering students' engagement, motivation and participation
- greater clarity on the need to promote inclusion in the classroom in engineering education.

This workshop intends to collaborate on empowering educators to unlock the full potential of all engineering students, regardless of their level of extroversion, ensuring a more inclusive and effective learning experience. Afterall, being shy, quiet, or introverted is not a problem to be fixed—it's a difference to be respected and supported.

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Workshop - Supercharging Your Engineering Classes with Ethics!

Shannon Chance^{1,2}

¹ TU Dublin, Ireland

² University College London, UK

Email: shannon.chance@tudublin.ie

DOI: <https://doi.org/10.5281/zenodo.15918775>

Abstract

Are you ready to energize your students' learning of engineering ethics? Join us for a high-voltage, interactive workshop where we'll unlock the power of the **Routledge International Handbook of Engineering Ethics Education**—an open-source treasure trove of cutting-edge knowledge and active learning strategies! This dynamic workshop is designed for educators who want to infuse their courses with innovative, discipline-specific ethics learning methods. Through gamified exploration, creative brainstorming, and collaborative problem-solving, you'll walk away with practical strategies to integrate ethics into any engineering course. We'll kick things off with a dynamic guided tour of the handbook, unveiling its structure and offerings. Then, we'll divide into small teams for a high-energy brainstorming game to connect ethics education with various engineering topics using active learning pedagogies. Each team will get a custom "**Engineering Ethics Education Bingo 1.0**" card, and the first team to complete a row and defend their ideas wins bragging rights as Ethics Bingo Champions! Then, we'll gear down and give some thoughtful consideration to designing curricula to implement when we get home.

Keywords: Engineering Ethics Education; Active Learning; Teaching Methods; Ethics.

1 Introduction

This workshop will familiarize engineering educators with the content of *The Routledge International Handbook of Engineering Ethics Education* (Chance, Børsen et al., 2025), an open-source compendium of state-of-the-art knowledge and practice and help them apply the themes from the book. The 90-minute workshop adopts an active learning format inspired by events at the 2024 International Conference in Active Learning in Engineering Education. The workshop features active learning and project-learning approaches in engineering education, with a focus on integrating ethics using case studies (Herzog et al., 2025), problems via challenges and problem-based learning (Routhe et al., 2025), value-sensitive design (Gammon et al., 2025), service learning and humanitarian engineering (Daniel et al., 2025), arts-based methods (Hitt et al., 2025), and reflective approaches and dialogical approaches (Marin et al., 2025). Our motivation is to:

- celebrate the handbook,
- help educators know where to find it, what's in it, and how to use it,
- help them envision applying ethics-based activities into the modules they teach, and
- model the application of active learning approaches so they experience both fast and slow thinking.

The workshop will implement and further test a new game for learning about ethics in various engineering disciplines (we hope to present that tool as a paper at this same conference and then demonstrate its implementation as one part of this hands-on workshop). The workshop relates directly to the following conference themes:

- Inclusion, diversity, and ethics in Engineering Education
- Active Learning and PBL Approaches
- Education for sustainability
- Curriculum design
- Teacher's Professional Development for Active Learning

2 Activities

This workshop will involve the following activities:

- 1) A brief introduction to the handbook with quick identification of the six sections/thematic areas of the book and note of the active teaching methods and specific disciplines featured (10 minutes).
- 2) A fast-paced brainstorming activity called "Engineering Ethics Education (EEE) Bingo 1.0" (Chance, Murphy, Leão, Tobosaru, & Nolan, in review) in groups of 3-4 (35 minutes).
- 3) A whole-group recap on the Bingo game, collecting recommendations for improvement (10 minutes).
- 4) A more deliberative activity in which groups develop one specific idea (generated from, during, or following the Bingo game) into a specific plan for how to implement it in the courses they teach (30 minutes).
- 5) Wrap-up synthesizing discussion (5 minutes).



Figure 1. Pilot testing an earlier version of the bingo card at the 2025 SEFI Ethics Spring Symposium in Ireland.

3 Expected results

This submission should clearly state what the participants will achieve and/or deliver at the end of the workshop. This is not necessarily a concrete product but could also be the outcomes of a discussion.

By the end of this workshop, participants will be able to:

- name some topics covered in *The Routledge International Handbook of Engineering Ethics Education*,
- access the open-source book online.
- work in a small group to establish relationships between assignment/activity ideas, ethics topics, discipline areas, and teaching methods.
- develop ideas for applying ethics topics, discipline areas, and teaching methods in their classrooms.

4 Conclusions

In conclusion, the workshop will open with an overview of the handbook (explaining its structure, purpose, and content), assembling small teams for a group brainstorming game using a bingo card, and then zooming in to apply methods explored in the handbook for embedding ethics education via active learning approaches (case studies, project- and challenge-based learning, value-sensitive design, service- and humanitarian-learning, arts-based methods, and reflective and dialogical approaches). We will consider how to apply these techniques in various engineering disciplines (civil, mechanical and aerospace, electronic and electrical, chemical, and software) and/or the types of engineering courses the participants teach (e.g., foundational classes on thermodynamics, chemistry, physics, calculus, design).

RIHEEE Ethics Bingo Card #10

Case Studies	Project-Based Learning	Arts-Based Methods	Value-Sensitive Design	Service Learning
14) Electrical Eng. Power Systems	3) Software Eng. Inclusive Tech Design	22) Aerospace Eng. Human Spaceflight Ethics	9) Mechanical Eng. 3D Printing & Bioethics	17) Civil Eng. Affordable Housing Design
7) Chemical Eng. Waste Reduction & Recycling	21) Mechanical Eng. Drones & Public Safety	5) Software Eng. Social Media & Misinformation	13) Electrical Eng. Neural Interfaces	25) Aerospace Eng. Drone Warfare Ethics
19) Civil Eng. Water Resource Management	11) Software Eng. AI Bias in Hiring	1) Mechanical Eng. Exoskeleton Ethics	16) WILD CARD! (Any method, any discipline!)	8) Chemical Eng. Sustainable Packaging
4) Electrical Eng. Facial Recognition & Privacy	24) Civil Eng. Public Transportation Ethics	10) Aerospace Eng. Climate Change & Aviation	20) Mechanical Eng. AI in Manufacturing	2) Software Eng. Predictive Policing & Bias
15) Chemical Eng. Food Engineering & Ethics	12) Mechanical Eng. Smart Prosthetics	18) Electrical Eng. Cryptocurrency & Sustainability	6) Software Eng. Dark Patterns in UX	23) Aerospace Eng. Orbital Debris & Responsibility

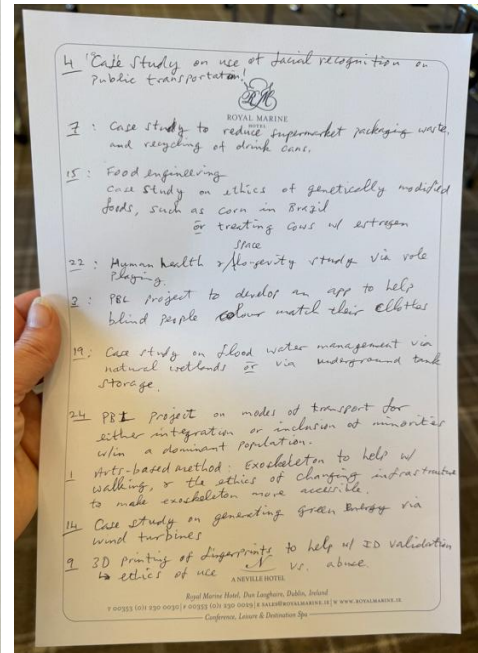


Figure 2. Featured outputs of the pilot test from the 2025 SEFI Ethics Spring Symposium, illustrating the range of active learning situations one team discussed.

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Workshop - What Really Drives Students to Learn? A Lean Coffee Discussion

José Dinis-Carvalho¹

¹ ALGORITMI Centre, Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal

Email: dinis@dps.uminho.pt

DOI: <https://doi.org/10.5281/zenodo.15918999>

Abstract

How can we promote greater engagement and motivation among engineering students? Despite the increasing implementation of active learning strategies, many educators still face challenges in maintaining students' enthusiasm, autonomy and sustained interest. This interactive workshop invites participants to reflect collaboratively on these questions using the Lean Coffee format - an agile, participant-driven discussion method that allows groups to self-organise around shared concerns and priorities. Instead of following a fixed agenda, participants will co-create the flow of the session by proposing, voting on and discussing topics related to student engagement and motivation in engineering education. This open structure promotes a more inclusive and reactive environment where diverse experiences and ideas can emerge. By the end of the workshop, participants will have exchanged practical strategies, identified common challenges and jointly developed ideas for improving teaching practices and institutional support systems. The session aims not only to share knowledge, but also to inspire ongoing dialogue and action in the participants' local contexts.

Keywords: Student Engagement; Engineering Education, Lean Coffee.

1 Introduction

Student engagement and motivation strongly influence the learning effectiveness as well as the general effectiveness of education systems. Student engagement and motivation in engineering are widely discussed topics in academic literature. A simple search in the Scopus database using the query ("student engagement" OR "student motivation") AND engineering) yields 5,144 published articles, in a search within Article title, Abstract, and Keywords. This number of articles highlights the significance of this research area.

Some work has been done on how to measuring student engagement, specially through surveys (Maskell & Collins, 2017) (Naibert & Barbera, 2022), as well on how to measuring student motivation (Hauze & Marshall, 2020) (Becerra & Almendra, 2020). In many of those articles the authors provide evidences that the motivation or engagement of students was the result of using some kind of innovation in teaching, specially through active learning approaches (Hernández-de-Menéndez et al., 2019). Examples are through the introduction of gamification (Figueiredo & Garcia-Penalvo, 2020), or in the use of Problem or Project Based Learning (Montero & Gonzalez, 2009) (Alves et al., 2016), or by the use of Flipped Classroom (Lucke & Christie, 2016), or Inquiry-Based Learning (Corral-Barraza et al., 2024).

Although extensive research has been published in books, journals, and conference proceedings, the complexity of the subject highlights the need for further exploration, knowledge generation, and experimentation. To address this gap, this workshop will facilitate dynamic discussions in a Lean Coffee format, bringing together academics to exchange insights and advance the field.

Lean Coffee is a structured, participant-oriented discussion format in which participants collaboratively set the agenda, prioritise topics and engage in time-limited conversations. Unlike traditional meetings with fixed agendas, Lean Coffee allows the group to focus on the most relevant and interesting topics in real time, ensuring a productive and democratic dialogue. Developed in 2010 by organizational consultants Benson and

Lightsmith, this approach applies Lean thinking principles to collaborative discourse, emphasizing value creation through the elimination of procedural waste. The methodology operates through an iterative process wherein participants first generate and prioritize discussion topics democratically, followed by timed conversational intervals that may be extended through collective agreement. This format ensures substantive dialogue while maintaining equitable participation opportunities. Originally conceived within Agile software development communities, the technique has gained broader scholarly and professional adoption due to its demonstrated efficacy in fostering engaged, productive discussions across educational, corporate, and research contexts. The approach's academic significance lies in its empirical validation of emergent agenda-setting as an effective alternative to predetermined meeting structures, particularly in contexts requiring collaborative knowledge construction.

2 Activities

Preparation (10 minutes). Participants will be invited to sit around one or more tables to promote equal participation (as shown in Figure 1). Sticky notes will be delivered for generating topics, as well as a timer to manage the discussions. Briefly explain will be give about the format of Lean Coffee, emphasising that the agenda will be crowd-sourced and time-bound. The necessary ground rules will be established, such as respecting speaking time and encouraging active listening.



Figure 1. Lean Coffee look.

Topic Generation and Prioritization (15 minutes): Participants will be invited to write down proposals of discussion topics - one per sticky note - and briefly describe each one to the group. All suggestions will be collected and displayed in a board next to the table. Then, a dot-voting process will be conducted: Each participant will have 4 votes (using dots on the sticky notes) to prioritize the most relevant topics. The sticky notes will then be placed in order of votes, creating the discussion agenda.

Time-Boxed Discussions (7 Minutes per Topic): Start with the highest-priority topic and the timer will be set to 7 minutes. The conversation will proceed organically, with participants sharing insights, questions, and perspectives. When the timer ends, the group will decide whether to extend the discussion (by another few minutes) or move to the next topic. This ensures that no single topic dominates the session unless there is strong collective interest.

Closing and Reflection (5–10 minutes): Once all prioritized topics have been addressed or time runs out, conclude with a brief reflection. Ask participants to share key takeaways or feedback on the process. This step helps reinforce learning and provides insights for improving future sessions. Optionally, document action items or unresolved questions for follow-up discussions.

3 Expected results

One of the main expected outcomes is a prioritised list of student engagement and motivation issues that participants believe are most important to address. These might include topics such as the impact of curriculum design on engagement and motivation, the role of real-world projects, the influence of teaching styles or the availability of support resources. Through time-limited discussions, participants can delve into each topic in a targeted way, allowing for meaningful dialogue without the meeting being dominated by a single question or voice.

Another important result is the emergence of actionable ideas. Participants are likely to identify practical measures to improve engagement, such as implementing more project-based learning, setting up peer mentoring programmes or increasing opportunities for students to participate in course design. These suggestions can be documented and used to inform programme improvements or future initiatives. The workshop can also help reveal common frustrations or systemic barriers, laying the groundwork for long-term strategies to improve the academic experience.

Finally, the session is expected to foster stronger communication and a sense of shared responsibility among participants. By taking part in a format that values all voices equally, participants empathise with each other's perspectives and contribute to a better understanding of the academic experience.

4 Conclusions

At the end of this workshop, participants will certainly have experienced an interesting and collaborative exchange of ideas, centred on one of the most present challenges in engineering teaching/learning: how to effectively motivate and involve students. Through the Lean Coffee format, participants will not only share their concerns and classroom realities, but also identify concrete strategies and approaches and opportunities for change. The open and participatory nature of the session allows educators to draw on their own experiences while learning from others, creating a sense of community and shared purpose. Ultimately, this workshop aims to trigger new understandings on the subject and inspire practical innovations to the context that can increase student motivation and learning in various engineering programmes.

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Workshop - Inclusion of ethics in engineering education: “Ethic pills”

Miguel Romá¹

¹ Group of signals, systems and telecommunication – SST. University of Alicante, Spain

Email: miguel.roma@ua.es

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Abstract

This proposal outlines a hands-on session, a revised iteration of a similar workshop presented at PAEE/ALE'2023. Despite broad consensus on the necessity of incorporating an ethical dimension into engineering studies, a dedicated course on engineering ethics is absent in many engineering degree programs. The proposed workshop aims to facilitate participants in exploring methodologies for integrating ethical considerations into existing courses, irrespective of the primary subject matter. The session will delve into strategies for selecting pertinent ethical topics, whether directly related to the course content or otherwise, and integrating them effectively within the course structure.

Keywords: Ethics in engineering; Ethics in engineering education; Active Learning.

1 Introduction

The promotion of reflection on ethical issues, alongside other generic competencies, is widely recognized as essential in the educational development of future engineers. A complete review about the relevant aspects of ethics in engineering education can be found in Chance et al. (2025). However, the emphasis on technical knowledge within many engineering curricula often limits the allocation of syllabus space for the specific cultivation of transverse competencies. The lack of dedicated space for ethics within technical courses represents a significant institutional barrier, as noted by researchers such as Walczak et al. (2010) and Davis (2006). Illustrative of this challenge, the Telecommunication Engineering degree at the University of Alicante includes “the ethical responsibility of engineering work” as a stated learning objective, yet lacks any compulsory or elective courses specifically addressing ethical issues. The study conducted by Walczak et al (2006) identified five prevalent obstacles to integrating ethics into engineering curricula:

- Curricular saturation limiting space for ethics education.
- Insufficient faculty training in teaching ethics.
- Lack of incentives for faculty to incorporate ethics.
- Inconsistent policies regarding academic dishonesty.
- Institutional growth straining existing resources.

The literature proposes various approaches for introducing ethics into engineering education, including a systematic framework presented by Li and Fu (2010).

Notably, findings from the Board of European Students of Technology Symposium (BEST, 2006) indicate a clear student demand for discussions on ethics and critical thinking within engineering education. The symposium also highlighted common challenges encountered when ethics courses are included in engineering programs:

- Talking about the inclusion of ethics in current university education there are different situations:
 - Complete specific course on ethics.
 - Integrated in some other courses – based on the will of the teachers or part of the program of the course.
 - The students are not taught ethics at all.

- Even if ethics is taught in some universities, like in the first two cases, it can be problematic in some situations:
 - The course is elective and not all the students are taking part because of the big number of courses they can choose.
 - The material is extensively theoretical.
 - Professors have no proper approach and make the course not attractive and tedious. The methods that are used are inappropriate.

Acknowledging student perspectives is crucial for designing effective and well-received ethics-related activities. Student suggestions often emphasize the need for:

- The course should give a direction of thinking that would make people more aware of their actions. By introducing a certain level of criticism, automatic behaviour would be excluded from decision making.
- Students generally would like to have interaction among all the students that enrolled the course and the teacher. It is a way through which more ideas could come up and more sharing could exist.
- The course should include case studies, examples from real life, problem-solving methods. The course should represent a lot of examples from real life.
- Dynamic course: as the time is changing the material should also change. The technologies are changing, so the courses should take it into account.
- About the people who will teach the course there were more ideas:
 - The person should have not just theoretical knowledge but also a practical background, the person should have experience as working as an engineer or as an option, special training on ethics.
 - Cooperation among two persons: engineer who will be practical and philosopher who will be theoretical.

Based on prior research involving engineering students at the University of Alicante, Table 1 presents topics frequently cited as desirable for inclusion in ethics sessions.

Table I. Topics to be included according to students' opinion.

	Topic	%
1	Acting in accordance with personal principles	25
2	Social/environmental impact of work	22
3	Personal attitude (confidence, personality, commitment...)	13
4	Fair labour market/labour intrusiveness	10
5	Economic considerations	10
6	Professionalism	10
7	Other unclassified aspects	10

2 Activities

The primary objective of the hands-on session is to demonstrate practical methods for incorporating ethical considerations into any engineering course, aligning where possible with student preferences for such activities. Davis (2006) advocates for 'micro-insertion' as a technique to integrate ethics into technical courses minimally disruptively and in a manner valued by students. Furthermore, there is broad consensus, as highlighted by Harris et al. (1996), that case studies represent an optimal method for teaching professional ethics. Techniques such as "drawing the line" and analyzing conflict cases are effective modes for addressing ethical dilemmas within case studies. Participants will be organized into small, diverse groups to encourage varied perspectives. The session will introduce a methodology combining micro-insertion with case studies

(termed "ethic pills") for integrating ethics in contexts where dedicated courses are unavailable. The proposed session structure is as follows:

- Topic presentation.
- Warm-up activity.
- Group activities (ethics pills).
- Discussion.
- Conclusion.

3 Expected results

During the session, participants will engage with the proposed activities from a student perspective. The most significant insights are anticipated to emerge from the subsequent discussion phase. Feedback regarding the perceived utility of the proposed methodology and suggestions for enhancing its effectiveness and engagement will be particularly valuable.

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Workshop - How to Develop a Chatbot in Less Than 90 Minutes: Hands-On Workshop on Emerging Technologies for Active Learning

Erik T. Lopes¹, Diana Mesquita²

¹ ALGORITMI Centre, Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal

² Universidade Católica Portuguesa, Faculty of Education and Psychology, Research Centre for Human Development, Porto, Portugal

Email: erik.lopes@algoritmi.uminho.pt, dmesquita@ucp.pt

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Abstract

In recent years, the rapid advancement of digital technologies, particularly generative artificial intelligence (AI), has significantly influenced how teaching and learning are designed, delivered, and experienced within higher education. One notable and increasingly relevant application is using chatbots as supportive tools for educators and students. Chatbots can reduce administrative workload, enhance student engagement, and enrich pedagogical strategies by facilitating active learning and personalised support. Despite their potential, these tools remain underexplored in many academic environments. This workshop offers an accessible and practice-oriented introduction to chatbot development, aimed at participants from all disciplines, regardless of their technical background. Through a structured six-step methodology and the use of Microsoft Copilot Studio, attendees will be guided through designing, building, and deploying a functional chatbot for active learning. The session combines theoretical insights with hands-on activities, including discussions on the broader implications of AI in education, exploration of advanced platform features, and critical reflections on technical and pedagogical limitations. By the end of the experience, each participant will have created a chatbot prototype applicable to their teaching practices or personal projects and will have gained a deeper, more critical understanding of the challenges and opportunities presented by artificial intelligence in contemporary educational contexts.

Keywords: Active Learning; Engineering Education; Chatbot; Artificial Intelligence.

1 Introduction

The development of new technologies and their impact on education has become an increasingly prominent topic of discussion in recent years (Souza & Debs, 2024). On the one hand, this context highlights the need to equip students with digital skills and competencies demanded by the labour market (González-Pérez & Ramírez-Montoya, 2022; Souza & Debs, 2024). On the other hand, using technology as a facilitative tool, reducing workload, enhancing engagement, and enriching learning strategies, has taken centre stage in pedagogical discourse (González-Pérez & Ramírez-Montoya, 2022). With the popularisation and accessibility of generative artificial intelligence language models in 2023, this debate has gained further traction, bringing discussion regarding assessment and plagiarism, for example.

In this context, a relatively simple yet still underutilised solution is the use of chatbots. These have been applied in academic settings to support educators, assist students, and streamline back-office tasks (Ramandanis & Xinogalos, 2023). Recent advancements in artificial intelligence have made chatbot development faster, simpler, and more accessible, even for professionals without a technical background in programming (Lopes et al., 2024).

Universities have produced numerous studies on applying active learning methodologies in engineering education (Lima et al., 2024). Approaches such as project-based learning, simulations, project management, and gamification have proven effective in enhancing student learning outcomes (Lima et al., 2023; Lopes &

Aquere, 2021; Pereira et al., 2018). In this light, the integration of chatbots and other digital technologies has emerged as a natural progression in pursuing educational improvement.

Drawing upon prior experience in developing educational chatbots, this workshop aims to share a six-step methodology that enables participants, regardless of their background in information technology, to design and implement a chatbot for a variety of educational purposes. Beyond creating a functional prototype, the workshop seeks to place participants in the position of a developer, thereby broadening their understanding of educational technologies and fostering more meaningful discussions regarding opportunities, challenges, and limitations.

The workshop consists of a hands-on session in which participants will build a chatbot in under 90 minutes for active learning. It will engage participants in collaborative discussions and interactive activities designed to deepen their perspectives on the use of emerging technologies in education. No prior technical knowledge is required; participants only need a Microsoft access to take part. During the workshop, one example will be developed, but participants are encouraged to bring their own resources (such as presentations, exercises, and notes) to train a chatbot tailored to their specific context.

2 Activities

The workshop will feature a combination of theoretical and practical activities, with the objective that by the end of the session, all participants will have learned how to deploy a chatbot suitable for use in their teaching practice, classes, or personal projects. Microsoft Copilot Studio will be employed as the primary tool, with participants engaging individually and collaboratively through active learning methodologies. The workshop is structured around six key phases:

1. **Theoretical Introduction:** A brief overview of the current context surrounding artificial intelligence, chatbot development, and key applications in active learning. The session will conclude with a *think-pair-share* activity during which participants define the focus of the chatbot they intend to develop. This segment aims to provide foundational knowledge and stimulate initial project ideation.
2. **Designing a Chatbot in Six Steps:** Participants will be introduced to the six-step methodology proposed by Lopes et al. (2024), with illustrative examples and a discussion of the key elements in each phase: Initial analysis; Definition of characteristics; Design; Implementation; Testing; and Evaluation. A template will be provided to help participants outline their chatbot concept, including its features, functionalities, and content.
3. **Chatbot Development:** This is the main hands-on segment of the workshop, where participants will follow a guided process using Copilot Studio. Demonstrations will be interspersed with practical exercises so that each participant can learn how to develop a chatbot tailored to their specific context. Topics covered include an overview of the platform, basic setup, providing knowledge sources, publishing options, and best practices for testing the prototype.
4. **Advanced Features:** This segment will present additional features of Microsoft Copilot Studio, including flow automation, integration with tools such as Power Virtual Agents, Microsoft Teams, and others within the platform. The goal is to inspire future further exploration beyond the scope of the workshop.
5. **Limitations and Alternative Tools:** A brief presentation of the limitations encountered during chatbot development, with comparisons to other tools on the market. Participants will be invited to share their experiences, identify difficulties, and reflect on limitations discovered during the session.
6. **Final Discussion and Evaluation:** The workshop will conclude with a final discussion of the development process, its challenges and opportunities, and the completion of a questionnaire collecting both

qualitative and quantitative feedback on the six-step methodology and perceptions of chatbot use in active learning.

3 Expected results

Each participant will leave the workshop with a tangible outcome: a chatbot prototype for active learning, personal projects, or other endeavours. In addition, the session will generate outputs from the discussions held throughout.

Through this interactive, hands-on experience, participants are expected to not only develop and deploy a chatbot but also deepen their understanding of generative artificial intelligence, including its potential, limitations, and implications. Discussions will address these aspects in relation to higher education and emerging technologies more broadly. By engaging in this project-based format, participants are expected to expand their perspectives on a topic of growing relevance in contemporary education.

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