
# PAEE/ALE 2024

## International Conference on Active Learning in Engineering Education

### Overcoming uncertainty - Building bridges between society and learning in the future

July 25-26, 2024

San Andrés Island -Colombia

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PROJECT
APPROACHES
IN ENGINEERING
EDUCATION

ALE

# *TITLE*

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21st Active Learning in Engineering Education Workshop (ALE)
San Andrés - Colombia, 24-26 July 2024

## *Editors*

Fernando José Rodríguez Mesa, Miguel Roma, Ximena Lopez, Rui M. Sousa, Anabela Alves, Rui M. Lima

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Department of Production and Systems – PAEE association

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http://paee.dps.uminho.pt/

This is a digital edition.

# WELCOME TO PAEE/ALE'2024

Dear participant,

Welcome to the PAEE/ALE2024 International Conference on Active Learning in Engineering Education. PAEE and ALE enhance active problem-based learning in engineering education. The conference merged two events: The International Symposium on Project Approaches in Engineering Education (PAEE), organised by the PAEE Association in 2009, and the Active Learning in Engineering Education Workshop (ALE), organised by the Active Learning in Engineering Education Network in 2000.

The conference theme for this year is "Overcoming uncertainty - building bridges between society and learning in the future." The main topics discussed during the conference were access to tertiary education in areas of poverty or disadvantage, addressing new cultural behaviours and technologies for engineering education, and extending to other disciplines. These discussions addressed the social difficulties, low intrinsic and extrinsic motivation for study, and the capacity to deal with these issues.

At a time characterised by swift technological progress and unprecedented global challenges, engineering education is experiencing significant changes. It has become increasingly crucial to prepare future engineers with technical know-how and the skills to tackle uncertainties and address complex societal issues. The theme "Overcoming Uncertainty - Building Bridges Between Society and Learning in the Future" captures this necessity, emphasising the vital role of innovative educational approaches in shaping resilient, adaptable, and socially conscious engineers.

The conference theme, "Bridging the Gap: Overcoming Uncertainty in Engineering Education is a comprehensive compilation of cutting-edge research, practical insights, and visionary approaches presented at the PAEE/ALE 2024 conference. The 71 works included in this volume provide a rich tapestry of strategies and methodologies designed to enhance engineering education and address the multifaceted challenges of the 21st century.

The works covered various topics, each contributing uniquely to an overarching theme. By integrating active learning and project-based methodologies to apply artificial intelligence and digital twins, these studies showcase innovative approaches that bridge the gap between theoretical knowledge and real-world applications. The diverse range of studies also emphasises the importance of interdisciplinary collaboration, ethical considerations, and the development of sustainable engineering practices.

Key Themes and Contributions

1. Several studies have focused on implementing active learning strategies such as using Lean Cards to teach Lean Manufacturing concepts, hands-on sessions exploring AI in engineering learning, and innovative pedagogical practices for teaching ethics. These studies highlight the significance of actively engaging students in learning to enhance their understanding and retention of complex concepts.
2. Project-based learning (PBL) and innovation have emerged as pivotal approaches in several studies. These projects demonstrate how PBL can cultivate innovation, problem-solving abilities, and resilience among students by fostering social entrepreneurship through hackathons and developing coping skills among engineering students through participatory action research.
3. Advanced technologies have significantly impacted education, as demonstrated by research in augmented reality, digital twins, and virtual reality (VR) laboratories. These tools have proven to enhance student engagement and offer immersive learning experiences, preparing students for success in a technology-driven world. Therefore, incorporating digital competencies is essential.
4. Studies on Collaborative Online International Learning (COIL), interdisciplinary design projects, and peace engineering underscore the importance of interdisciplinary approaches and global collaboration. These initiatives foster a holistic understanding of engineering challenges and promote the development of global competencies.
5. Sustainability is a recurring theme, with studies addressing the integration of sustainable engineering practices into curricula and the development of competencies to address global challenges. Projects such as the rainwater potabilisation system for rural schools exemplify the impact of engineering solutions on community well-being and environmental stewardship.
6. The inclusion of ethics in engineering education has been highlighted in various cases, emphasising the need to equip engineers with the ethical framework necessary to make responsible decisions. Humanitarian engineering projects further illustrate the role of engineering in addressing societal needs and fostering inclusive developments.

This compilation is a testament to the dynamic and evolving nature of engineering projects. The insights and innovations presented herein address the current educational challenges and lay the groundwork for future research. By bridging the gap between society and learning, these studies exemplify the potential of engineering education in cultivating skilled professionals and proactive, ethical, and globally aware citizens. As we move forward, the collective efforts shown in this volume will undoubtedly contribute to the continuous improvement and transformation of engineering education, ensuring that it remains responsive to society's needs and capable of overcoming future uncertainties.

Fernando Rodríguez Mesa & Miguel Roma

(Chairs of the PAEE/ALE'2024)

# PAEE/ALE'2024 Organization

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# PAEE/ALE'2024 Scientific Committee

| Scientific Committee | Affiliation |
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| Anabela Alves | University of Minho |
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| Benedita Malheiro | Instituto Superior de Engenharia do Porto and INESC TEC |
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| Carola Hernandez | Universidad de los Andes |
| Celina P. Leao | University of Minho |
| Chin-Yin Huang | Tunghai University |
| Crediné Menezes-Crediné | UFRGS |
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| Walter Nagai | UNIFEI |

# PAEE/ALE'2024 Invited Speakers

PAEE/ALE'2024 attracted renowned keynote speakers from different sectors to share their viewpoints on the direction of education, especially in engineering education in this new era. We are honoured to have the following inspiring keynote speakers:

## Pau Bofill I Soliguer

### Navigating Engineering Education for the Jobs of the Future: A Conversation – A workshop

Professor at the Escola Politècnica de Telecomunciació (Universitat Politècnica de Catalunya – Barcelona Tech), where he teaches computer programming. He has been interested in active learning since 1994 and he has participated in a number of conferences in this field, including ALE and PALE. He was a member of the Humanities, Technology and Society reflection group (at the UPC). He is concerned with the risks of technology and the current economic system, which lead our civilization to exponential growth.

## Erik De Graaff

### Empowerment of Students. subtitle PBL as a tool for change

Trained as psychologist and holds a PhD in social sciences. He has been working with Problem Based learning (PBL) in Maastricht from 1979 till 1990. After completing his PhD, he joined Delft University where he was appointed as associate professor in the field of educational innovation at the Faculty of Technology Policy and Management. Dr. de Graaff has been a visiting professor at the University of Newcastle, Australia in 1995 and several times a guest professor at Aalborg University in Denmark. The collaboration with Aalborg University resulted in an appointment as professor MSO at the department of Development and Planning in 2011. He retired in 2022. Dr. de Graaff is widely recognized as an international expert on PBL. He contributed to knowledge and understanding of higher engineering education with numerous publications and through active participation in professional organizations like SEFI, IGIP, IFEES and ALE. He has published over 200 articles and papers and he has presented more than 70 keynotes and invited lectures on various topics related to PBL in higher education, like: Working with PBL, Management of change, Assessment and evaluation, Methods of applied research and Collaboration between university and industry. From 2008 untill 2017 he was Editor-in-Chief of the European Journal of Engineering Education.

## Aida Guerra

### Sustainability education and the overcome of uncertainties - Student perspectives

Vice-director of Aalborg Centre for PBL in Engineering Science and Sustainability under the auspices of UNESCO and associate professor within the field of Problem-Based, Project-Organised Learning (PBL) and Engineering Education for Sustainable Development at the Department of Planning (Aalborg University, Denmark) and the Institute of Advanced Studies in PBL (Aalborg University, Denmark). She is trained in Biology and Geology Education (B.Sc.), Science Education, PBL and Sustainability (M.Sc.), and holds a PhD degree in PBL and Education for Sustainable Development in Science and Engineering Education. Dr Aida Guerra has been developing and doing research in the areas of curriculum development, continuing pedagogical development, engineering education for sustainable development, PBL, engineering global challenges, and competences for 21st century. Her current research focus is on PBL and the integration of sustainability in higher education, specifically in engineering education; student agency towards sustainability; staff readiness for change, and competences for sustainable development. She has published several articles, conference papers and has been given several international presentations and workshops within these fields all over the world. Dr Aida Guerra is also an active member of engineering education organisations, namely the governing board of REEN (Research in Engineering Education Network) and SEFI-Sustainability Interest Group.

# PAEE/ALE'2024 Programme

An overview of the program is shown below. The event occurs at the Convention Center, in the San Andrés Island, Colombia.

| | 24/07 | 25/07 | 26/07 |
|---|---|---|---|
| 08:00 | Registration (Convention Area Lobby) | | |
| 08:30 | Opening ceremony (Main conference room) | | |
| 09:00 | Ice-breaking integration activity - Bingo (Main conference room) | | |
| 9:30 | Keynote session - Aida Guerra (Main conference room) | Keynote session - Pau Bofill (Main conference room) | Keynote session - Erik de Graaff (Main conference room) |
| 11:00 | Coffee break (Convention Area Lobby) | Coffee break (Convention Area Lobby) | Coffee break (Convention Area Lobby) |
| 11:30 | Workshops 1, 2, 3 (smaller conference rooms) | Workshops 4, 5, 6 (smaller conference rooms) | Workshops 7, 8 (smaller conference rooms) |
| 13:00 | Lunch 🍽 | Lunch 🍽 | Closing event ceremony |
| 14:30 | Paper Sessions I, II, III (smaller conference rooms) | Paper Sessions VII, VIII (smaller conference rooms) | Visit to Caribe Campus- Botanical Garden - San Luis (lunch not included this day) |
| 16:00 | Break ☕ | Break ☕ | |
| 16:30 | Paper Sessions IV, V, VI (smaller conference rooms) | Student Paper Session (smaller conference rooms) | |
| 17:00 | | | Photo |
| 18:30 | Finish day | Finish day | |
| 19:00 | Conference Dinner - Aquamare | | |

# PAEE/ALE'2024 Detailed Programme

Details for each session are listed below.

## 24 July 2024

### 8:30 - 9:00: Opening ceremony (Main conference room)

- **Maria Alejandra Guzman** (Dean of Engineering in Bogota)
- **Adrian Santos** (Caribe-Campus- Director)
- **Miguel Romá** (Chair of the Active Learning in Engineering Education Network - ALE)
- **Rui Lima** (Chair of the Project Approaches in Engineering Education - PAEE)
- **Fernando Rodríguez Mesa** (General Organizer of the International Conference on Active Learning in Engineering Education - PAEE/ALE'2024)

### 9:00 - 9:30: Ice-Breaking activity (Main conference room)

### 9:30 - 11:00: Keynote session - Aida Guerra (Main conference room)

### Sustainability education and the overcome of uncertainties - Student perspectives

**Aida Guerra**

AALBORG UNIVERSITY – DENMARK

Vice-director of Aalborg Centre for PBL in Engineering Science and Sustainability under the auspices of UNESCO and associate professor within the field of Problem-Based, Project-Organised Learning (PBL) and Engineering Education for Sustainable Development at the Department of Planning (Aalborg University, Denmark) and the Institute of Advanced Studies in PBL (Aalborg University, Denmark). She is trained in Biology and Geology Education (B.Sc.), Science Education, PBL and Sustainability (M.Sc.), and holds a PhD degree in PBL and Education for Sustainable Development in Science and Engineering Education. Dr Aida Guerra has been developing and doing research in the areas of curriculum development, continuing pedagogical development, engineering education for sustainable development, PBL, engineering global challenges, and competences for 21st century. Her current research focus is on PBL and the integration of sustainability in higher education, specifically in engineering education; student agency towards sustainability; staff readiness for change, and competences for sustainable development. She has published several articles, conference papers and has been given several international presentations and workshops within these fields all over the world. Dr Aida Guerra is also an active member of engineering education organisations, namely the governing board of REEN (Research in Engineering Education Network) and SEFI-Sustainability Interest Group.

### 11:30 - 13:00: Workshops 1, 2, 3 (smaller conference rooms)

| # | Authors | Title |
|---|---|---|
| 1 | Rui M. Lima and Diana Mesquita | How to Plan an Interdisciplinary Project-Based Learning (PBL) Approach |
| 2 | Miguel Romá Romero and Pau Bofill | AI: ally or enemy for engineering learning? |
| 3 | Alexei Ochoa-Duarte and Leonardo León | Collective construction of a course on peace engineering syllabus from an interdisciplinary dialogue |

## 14:30 - 16:00: Paper Sessions I, II, III (smaller conference rooms)

### Session I - Inclusion and Sustainability (small conference room 1)

*Session chairs: Miguel Romá & Anabela Alves*

| # | Authors | Title |
|---|---|---|
| 3 | Gerardo Salvador González Lara and Martha Catalina Del Ángel Castillo | Interdisciplinary teaching of ethics and translation to university students to provide social service to children with disabilities. |
| 16 | Luiz Ney D'Escoffier, Aida Guerra and Marcia Terezinha Longen Zindel | Educational Strategies for Sustainable Futures: Revealing the Priorities and Perspectives of Engineering Students |
| 33 | Luana Thereza Nesi de Mello, Rafael Hauckewitz Todaro, Ana Cristina Caldeira, Cristiane Maria Barra da Matta and Guilherme Wolf Lebrão | Student inclusion as an institutional focus: report and implementation of support strategies for educating a visually impaired student in an Engineering program |
| 48 | Carola Hernandez and Nicolás Sánchez-Díaz | Ethics through the curriculum of the Faculty of Engineering |
| 58 | Juan Sebastián Sánchez Gómez, Angie Paola Hernandez and Libis Valdez Cervantes | The closing of the gender gap in the fourth industrial revolution with a feminist focus in Colombia |
| 95 | Juliana Zuluaga Carrero and Fernando Jose Rodríguez Mesa | Ecological Engineering Integration: A PBL Journey Towards Sustainability in Rural Project Contexts |

### Session II - Experiences on Active Learning (small conference room 2)

*Session chairs: Luciano Soares & Diana Mesquita*

| # | Authors | Title |
|---|---|---|
| 13 | Jose Pereira and Flavio Almeida | Risk Response Actions in the preparation of Undergraduate Final Project Reports – UFPR (Undergraduate Thesis) when using Project-Based Learning |
| 22 | Simone Borges Simão Monteiro, Rodrigo Pereira Gomes, Luis Guilherme Borges Monteiro, Ana Cristina Fernandes Lima, Everaldo Silva Junior and Gabriel de Lanna Fiuza Curi Garcia | Continuous evolution of The Unified Platform of Active Methodologies (PUMA): focus on integration between market and academia |
| 23 | Gabriel de Lanna Fiuza Curi Garcia, Simone Borges Simão Monteiro, Dianne Magalhães Viana and Jens Myrup Pedersen | Tailoring Portfolio, Program and Project Management to a Complex System |
| 43 | Denise Hirayama and Ésoly Madeleine Bento Dos Santos | Professor's experiences in Reflective Portfolio for Materials Engineering Program |
| 44 | Esoly Madeleine Bento dos Santos, Denise Hirayama, Tiago Brandão Costa and Emerson Carneiro Figueredo | Professors and Students Perception on the Implementation of Active Methodologies: A Case Study in the School of Industrial Metallurgical Engineering of Volta Redonda, Brazil |
| 101 | Gerardo Salvador González Lara, Carolina Sacristán Ramírez and Paloma Vargas Montes | Interdisciplinarity and technologies to recover the cultural heritage of northern Mexico |

### Session III - Innovative Experiences in Engineering Education (small conference room 3)

*Session chairs: Rui Lima & Ximena López*

| # | Authors | Title |
|---|---|---|
| 7 | Shannon Chance | Active Learning to Enhance the Architecture, Engineering, and Construction Sector |
| 10 | Afsaneh Hamedi D'Escoffier and Frederico Pifano de Rezende | Academic hackathon and PBL as an awakening of competencies for social entrepreneurship in engineering students |
| 19 | Sandra Liliana Rojas Martìnez and Sonia Esperanza Monroy Varela | Development of Coping Skills in Engineering Students to Overcome Emotional Challenges: A Participatory Approach from Project-Based Learning |
| 85 | Roman Leonardo Rodriguez Florian, Castro-Jimenez Laura Elizabeth and Jair Eduardo Rocha-Gonzalez | Interdisciplinary Integration in Engineering Education: Integration of Predictive Statistical Model Generation for Chronic Disease Prediction through Fingerprint Dermatoglyphics |
| 86 | Jens Myrup Pedersen, Katherine Ortegon, Henry Arley Taquez Quenguan and Angelica Burbano Collazos | Active Learning and New Technologies: Towards Better Learning |
| 88 | Jose M. Ramirez-Scarpetta, Julio E. Urbano-López, Esteban E. Rosero-García and Fabio G. Guerrero-Moreno | IoT Platform for Learning Control Systems |

*16:30 - 18:00: Paper Sessions IV, V, VI (smaller conference rooms)*

**Session IV - Development and Assessment of Competences (small conference room 1)**

*Session chairs: Miguel Romá & Ximena López*

| # | Authors | Title |
|---|---|---|
| 5 | Soraia Stabach Ribas Ferrari dos Santos, Deivison Ferrari dos Santos and Eloiza Aparecida Silva Ávila de Matos | Innovative Experiences in Engineering Education: Leveraging Continuous Improvement in the Automotive Industry |
| 41 | Leonidas Sandoval and Fabio Orfali | Prediction of academic performance by measuring autonomy for learning in an Engineering program |
| 42 | Alejandra González, Maria Leon and Hermes Vacca | Formative assessment in engineering courses at PUJ: Faculty perspectives on assessment. |
| 49 | Dianne M. Viana, Cristiane S. Ramos, Márcia R. Mortari, Eduardo Bessa and Sergio Antônio A. de Freitas | Learning Indicators as Tools for Continuous Improvement in the Educational Environment |
| 71 | Laura Ramírez and Andrés Ramirez-Portilla | Development of a Training Strategy for Consulting Sales Engineers in New Technologies for Business Solutions through Andragogy |
| 99 | Violeta Carvalho, Cristina Rodrigues, Senhorinha Teixeira, Ângela Silva, Rui Sousa, Lino Costa, Anabela Alves and Carina Pimentel | Transferable skills development through Project Based Learning in Industrial Engineering and Management Graduation |

**Session V - Basic Sciences in Engineering Education (small conference room 2)**

*Session chairs:* Shannon Chance & Fernando Rodríguez Mesa

| # | Authors | Title |
|---|---|---|
| 27 | Eduardo Torres-Rojas, Hernán Gustavo Cortés-Mora, Rosa Angélica Botello-Yañez, Carlos Enrique Ángel-Martínez, Leonardo David Donado, Adriana Patricia Piña and Martha Cristina Bustos-López | Making visible the invisible: Experiences on multidisciplinary outdoors groundwater teaching at Bogotá Campus |
| 54 | Liz Karen Herrera-Quintero, Maria Fernanda Lara-Diaz and Juan David Villegas-Tamayo | STEAM Classrooms: A Neuroscience-Based Educational Transformation Experience within UNAL's Digital Framework |
| 55 | Julian Mauricio Granados, Mariana Henao, Diego Alejandro Castrillon, Maria Leon and Carola Hernandez | Pedagogical strategies to stimulate the active participation of students in mathematics classes in higher education |
| 59 | Juan Sebastián Sánchez-Gómez, María Catalina Ramirez Cajiao and Karolayn Andrea Posada Casadiego | Trends of educational innovation in the higher education of Latin America |
| 62 | Gabriel Padilla and René Castillo | Visual representations and learning obstacles for definite integrals in undergraduate students |
| 87 | Javier Ramírez Angulo and Josefina Castillo Reyna | Towards an innovative framework for teaching electron configuration in chemistry courses using analogies |

**Session VI - Project Management in Engineering Education (small conference room 3)**

*Session chairs: Jens Pedersen & Pau Bofill*

| # | Authors | Title |
|---|---|---|
| 17 | Ivo Teixeira, Paulo Martins, Rui Sousa and Guilherme Pereira | Implementation of a Smart Manufacturing Systems Laboratory for Manufacturing Planning and Control |
| 18 | Micael Gonçalves, Ivo Teixeira, Paulo Martins and Guilherme Pereira | Active Learning in the development of Product Data Management competences in an Industrial Engineering and Management Master Program |
| 34 | Luciano Soares, Luciana Campos Lima and Raul Ikeda Gomes da Silva | Navigating Engineering Capstone Strategies |
| 40 | Anabela Tereso | Transforming the assessment method of multiple classes: the case of three Project Management curricular units at University of Minho |
| 47 | Silvia Tijo-Lopez and Guillermo Mejia-Aguilar | Active Learning in Construction Management Capstone Projects: Bridging Theory and Practice |
| 63 | Anabela C. Alves, Rui M. Lima, Diana Mesquita, Maria Teresa Malheiro and Celina P. Leão | Exploring eXtended-Based Learning Approaches in Portuguese Higher Education: A Study in Industrial Engineering and Management |

## *25 July 2024*

9:30 - 11:00: Keynote session - Pau Bofill (Main conference room)

***Necessity-centered education: building bridges between society and learning in the future.***

**Pau Bofill I Soliguer**

UNIVERSITAT POLITÈCNICA DE CATALUNYA – BARCELONA

Professor at the Escola Politècnica de Telecomunciació (Universitat Politècnica de Catalunya – Barcelona Tech), where he teaches computer programming. He has been interested in active learning since 1994 and he has participated in a number of conferences in this field, including ALE and PALE. He was a member of the Humanities, Technology and Society reflection group (at the UPC). He is concerned with the risks of technology and the current economic system, which lead our civilization to exponential growth.

***11:30 - 13:00: Workshops 4, 5, 6 (smaller conference rooms)***

| # | Authors | Title |
|---|---|---|
| 4 | Luciano Soares and Fabio Orfali | Development of Competency-Based Curriculum |
| 5 | Carola Hernandez, Nicolás Sánchez-Díaz and Carola Gómez | What does it mean to teach teamwork? |
| 6 | Shannon Chance | Active Learning Teaching Methods for Engineering Ethics Education |

***14:30 - 16:00: Paper Sessions VII, VIII (smaller conference rooms)***

**Session VI - Workspaces for Active Learning (small conference room 1)**

*Session chairs:* Shannon Chance & *Jens Pedersen*

| # | Authors | Title |
|---|---|---|
| 9 | Joao M. Silva, Paulo Celso R. Gomes, Simone B. S. Monteiro, Marcelo C. Gonçalves, Adriano P. Rosa, Henrique C. Ferreira, Mateus H. Torres and Clóvis Neumann | Active Learning Approaches for Introduction to Engineering Courses: University of Brasilia Production Engineering Case and Proposal for Tailoring the Framework to other Engineering Programs |
| 38 | Rosa Angelica Botello Yañez, Hernan Gustavo Cortes Mora and Eduardo Torres Rojas | Appropriation of the Territory and Active Learning through Environmental Interpretation Walks at the National University of Colombia, Bogotá Campus |
| 61 | Anabela C. Alves, Filipe Alvelos and Celina P. Leão | From Passive Learners to Active Participants: Empowering Engineering Students Through Experiential Learning |
| 84 | Jair Eduardo Rocha-Gonzalez, Jairo Rafael Coronado-Hernandez and Camilo Augusto Garcia-Guevara | Digital twins in serial production: A teaching methodology for prototyping in process design |
| 93 | Diana Mesquita and Rui M. Lima | Empowering Teachers for Active Learning in Higher Education: Contributions from an International Teacher Training Program |
| 98 | Fernando José Rodriguez-Mesa and Carlos A. Narváez-Tovar | Comparing motivation and reflection in project-work between TBL and PBL |

**Session VII - Active Learning and ICT Support (small conference room 2)**
*Session chairs: Miguel Romá & Ximena López*

| # | Authors | Title |
|---|---|---|
| 24 | Rasmi-Vlad Mahmoud, Marios Anagnostopoulos and Jens Myrup Pedersen | Active Learning and Cybersecurity Training: Best practices and recommendations on using Cyber Ranges |
| 32 | Pedro Henrique Emil Pinheiro Freme and Luciano Soares | Challenges of Teaching a Hands-on Virtual Reality Course |
| 35 | Liz Karen Herrera-Quintero and Fredy Andres Olarte-Dussan | Experience in the Implementation of a Permanence Strategy in Virtual Training in Technology |
| 50 | Crediné Silva de Menezes, Rosane Aragon, Alberto Nogueira de Castro-Jr and Andromeda Goretti de Menezes Campos | Pedagogical Architectures for the Development of Computational Thinking |
| 70 | Pradeeban Kathiravelu and David Moxley | Peer Learning in Diverse Undergraduate Population in Networking and Distributed Computing Research |
| 78 | Erik T. Lopes, Diana Mesquita and Rui M. Lima | Developing a Chatbot for Process Modelling Learning: contributions for active learning in engineering education |

## *16:30 - 18:30: Student Paper Session (Main conference room)*
*Session chairs: Jens Pedersen & Joana Chaves*

| # | Authors | Title |
|---|---|---|
| 4 | Soraia Stabach Ribas Ferrari dos Santos, Luis Mauricio Martins de Resende and Juliana Castanon Xavier | Project-Based Learning in Engineering Education: A Systematic Review of the Literature |
| 12 | Gabriel de Lanna Fiuza Curi Garcia, Luiz Henrique Fernandes Zamprogno, Luis Guilherme Borges Monteiro, Simone Borges Simão Monteiro, Dianne Magalhães Viana, Ana Cristina Fernandes Lima and Edgard Costa Oliveira | KPIs to measure impact of technology projects in the UN 2030 education agenda |
| 25 | Leonardo León and Alexei Ochoa-Duarte | Rainwater potabilization system: a PBL experience for the construction of approached technologies |
| 37 | Ana Caroline Braz, Marcus Jessé Oliveira, Carla Koike, Dianne Viana and Jones Yudi Silva | Enhancing Learning with Block Programming in Educational Robots |
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## 26 July 2024

9:30 - 11:00: Keynote session - Erik de Graaff (Main conference room)

### *Empowerment of Students: PBL as a tool for change*

**Erik De Graaff, PhD.**
AALBORG UNIVERSITY – DENMARK

Trained as psychologist and holds a PhD in social sciences. He has been working with Problem Based learning (PBL) in Maastricht from 1979 till 1990. After completing his PhD, he joined Delft University where he was appointed as associate professor in the field of educational innovation at the Faculty of Technology Policy and Management. Dr. de Graaff has been a visiting professor at the University of Newcastle, Australia in 1995 and several times a guest professor at Aalborg University in Denmark. The collaboration with Aalborg University resulted in an appointment as professor MSO at the department of Development and Planning in 2011. He retired in 2022. Dr. de Graaff is widely recognized as an international expert on PBL. He contributed to knowledge and understanding of higher engineering education with numerous publications and through active participation in professional organizations like SEFI, IGIP, IFEES and ALE. He has published over 200 articles and papers and he has presented more than 70 keynotes and invited lectures on various topics related to PBL in higher education, like: Working with PBL, Management of change, Assessment and evaluation, Methods of applied research and Collaboration between university and industry. From 2008 until 2017 he was Editor-in-Chief of the European Journal of Engineering Education.

### *11:30 - 13:00: Workshops 7, 8 (smaller conference rooms)*

| # | Authors | Title |
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| 8 | Miguel Romá Romero | The inclusion of technology and sustainability in engineering education: a realistic approach. |

### *13:00 - 13:15 Closing event ceremony*

### *15:00 - 19:00: Visit to Caribe Campus- Botanical Garden - San Luis (lunch not included this day)*

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# List of Authors

| Author | Affiliation | Country | # |
|---|---|---|---|
| Adriana Patricia Piña | Universidad Nacional de Colombia Sede Bogotá | Colombia | 27 |
| Adriano P. Rosa | University of Brasilia | Brazil | 9 |
| Afsaneh Hamedi D'Escoffier | Lab. Protozoologia, Instituto Oswaldo Cruz, Fundação Oswaldo Cruz - RJ | Brazil | 10, 51 |
| Aida Guerra | Aalborg Center for Problem-based Learning in Engineering Science and Sustainability, Aalborg University | Denmark | 16 |
| Alberto Nogueira de Castro-Jr | Universidade Federal do Amazonas | Brazil | 50 |
| Alejandra González | Pontificia Universidad Javeriana | Colombia | 42 |
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| Ana Cristina Fernandes Lima | Universidade de Brasilia | Brazil | 12, 22 |
| Anabela C. Alves | ALGORITMI/LASI Research Center, School of Engineering, University of Minho, Guimarães, Portugal | Portugal | 61, 63, 97, 99 |
| Anabela Tereso | ALGORITMI Centre, Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal | Portugal | 40 |
| Andrés Ramirez-Portilla | Tecnologico de Monterrey, Escuela de Ingeniería y Ciencias, Ave. Eugenio Garza Sada 2501, Monterrey 64849, NL, Mexico | Mexico | 71 |
| Andromeda Goretti de Menezes Campos | Federal Institute of Education, Science, and Technology of Espírito Santo | Brazil | 50 |
| Ângela Silva | ALGORITMI/LASI Research Center, School of Engineering, University of Minho, Guimarães, Portugal | Portugal | 99 |
| Angelica Burbano Collazos | Facultad de Ingeniería, Diseño y Ciencias Aplicadas, Universidad Icesi, Cali, Colombia. | Colombia | 86 |
| Angie Paola Hernandez | GISTIC, National University of Colombia | Colombia | 58 |
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| Carina Pimentel | ALGORITMI/LASI Research Center, School of Engineering, University of Minho, Guimarães, Portugal | Portugal | 99 |
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|---|---|---|---|
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| Katherine Ortegon | Facultad de Ingeniería, Diseño y Ciencias Aplicadas, Universidad Icesi, Cali, Colombia. | Colombia | 86 |
| Laura Ramírez | Centro de Investigación Pedagógica del Caribe, Universidad Pedagógica del Caribe, S.C., Cancún, México | Mexico | 71 |
| Leonardo David Donado | Universidad Nacional de Colombia Sede Bogotá | Colombia | 27 |
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| Luiz Henrique Fernandes Zamprogno | Universidade de Brasilia | Brazil | 12 |
| Luiz Ney D'Escoffier | Lab. Protozoologia; Instituto Oswaldo Cruz, Fiocruz | Brazil | 16 |
| Marcelo C. Gonçalves | University of Brasilia | Brazil | 9 |
| Marcelo Carneiro Gonçalves | Faculty of Technology, University of Brasilia (UNB), Brasília, Brazil. | Brazil | 14 |
| Márcia R. Mortari | University of Brasilia | Brazil | 49 |
| Marcia Terezinha Longen Zindel | Faculdade de Tecnologia, Departamento de Engenharia de Produção, Universidade de Brasília | Brazil | 16 |

| Author | Affiliation | Country | # |
|---|---|---|---|
| Marcus Jessé Oliveira | University of Brasilia | Brazil | 37 |
| María Catalina Ramirez Cajiao | Universidad de los Andes | Colombia | 59 |
| Maria Fernanda Lara-Diaz | Human Communication Department, Faculty of Medicine, Universidad Nacional de Colombia. | Colombia | 54 |
| Maria Leon | Pontificia Universidad Javeriana | Colombia | 42, 55, 56 |
| Maria Teresa Malheiro | Center of Mathematics (CMAT-UM), Department of Mathematics, School of Sciences, University of Minho | Portugal | 63 |
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| Martha Cristina Bustos-López | Universidad Nacional de Colombia Sede Bogotá | Colombia | 27 |
| Mateus H. Torres | Aalborg University | Denmark | 9 |
| Mateus Halbe Torres | Aalborg University | Denmark | 97 |
| Micael Gonçalves | ALGORITMI Centre, Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal | Portugal | 18 |
| Miguel Romá Romero | Group of signals, systems and telecommunication – SST. University of Alicante | Spain | 20, 21 |
| Natascha van Hattum-Janssen | Saxion University of Applied Sciences | Netherlands | 97 |
| Nicolás Sánchez-Díaz | Research assistant, Faculty of Engineering | Colombia | 48, 92 |
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| Paloma Vargas Montes | Tecnologico de Monterrey | Mexico | 101 |
| Pau Bofill | Universitat politècnica de Catalunya – Barcelona Tech, Barcelona | Spain | 21, 64 |
| Paulo Celso R. Gomes | University of Brasilia | Brazil | 9 |
| Paulo Martins | ALGORITMI Centre, Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal | Portugal | 17, 18 |
| Pedro Henrique Emil Pinheiro Freme | Insper | Brazil | 32 |
| Pradeeban Kathiravelu | University of Alaska Anchorage | United States | 70 |
| Rafael Hauckewitz Todaro | Instituto Mauá de Tecnologia | Brazil | 33 |
| Rasmi-Vlad Mahmoud | Aalborg Universitet | Denmark | 24 |
| Raul Ikeda Gomes da Silva | Insper | Brazil | 34 |
| René Castillo | Universidad Nacional de Colombia | Colombia | 62 |
| Rodrigo Pereira Gomes | Universidade de Brasilia | Brazil | 22 |
| Roman Leonardo Rodriguez Florian | Universitaria Agustiniana | Colombia | 85 |
| Rosa Angelica Botello Yañez | Universidad Nacional de Colombia | Colombia | 38 |
| Rosa Angélica Botello-Yañez | Universidad Nacional de Colombia Sede Bogotá | Colombia | 27 |
| Rosane Aragon | Universidade Federal do Rio Grande do Sul | Brazil | 50 |
| Rui M. Lima | ALGORITMI/LASI Center, University of Minho | Portugal | 63, 65, 78, 93, 97 |
| Rui Sousa | ALGORITMI Centre, Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal | Portugal | 17, 99 |
| Sandra Liliana Rojas Martìnez | Universidad Nacional de Colombia | Colombia | 19 |
| Senhorinha Teixeira | ALGORITMI/LASI Research Center, School of Engineering, University of Minho, Guimarães, Portugal | Portugal | 99 |
| Sergio Antônio A. de Freitas | University of Brasilia | Brazil | 49 |
| Shannon Chance | School of Architecture, Building & Environment, Technological University Dublin, Dublin, Ireland | Ireland | 7, 8 |
| Silvia Tijo-Lopez | Universidad Industrial de Santander | Colombia | 47 |
| Simone Borges Simao Monteiro | University of Brasilia | Brazil | 9, 12, 22, 23, 97 |
| Sonia Esperanza Monroy Varela | Universidad Nacional de Colombia | Colombia | 19 |
| Soraia Stabach Ribas Ferrari dos Santos | UTFPR | Brazil | 4, 5 |
| Taciana Gatto | Secretaria de Educação do Estado do Rio de Janeiro | Brazil | 51 |
| Thiago Vidal de Sá | Department of Industrial Engineering, Pontifical Catholic University of Paraná (PUCPR), Curitiba, Brazil. | Brazil | 14 |
| Tiago Brandão Costa | Fluminense Federal University | Brazil | 44 |
| Violeta Carvalho | ALGORITMI/LASI Research Center, School of Engineering, University of Minho, Guimarães, Portugal | Portugal | 99 |

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# PAEE/ALE’2024 Submissions

The PAEE/ALE’2024, 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 ALE Network, since 2000. PAEE/ALE’2024 aims to join teachers, researchers on Engineering Education, Deans of Engineering Schools and professionals 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.
- **Hands-on and Workshop submissions**, aiming to encourage discussion of current practice and research on project approaches.
- **Abstract submissions**, which is a short submission that may be included in paper session presentations or poster sessions presentations.

All full paper submissions were double reviewed by the PAEE/ALE’2024 scientific committee, 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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- Ensure confidentiality of submissions and reviews.
- Reviewers do a fair and detailed review of paper(s) assigned to them.

# PAEE/ALE'2024 List of Submissions

## PAEE/ALE’2024 Position Paper

Submission accepted as a position paper.

# Necessity-centred education: building bridges between society and learning in the future

Pau Bofill[1]

[1] Col·lectiu Mostassa. Universitat Politècnica de Catalunya - Barcelona Tech

Email: pau.bofill@upc.edu

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**Abstract**

The principle of regenerative agriculture is to focus on the soil and nurture it with microorganisms, minerals and organic matter, so that plants can grow healthy and the land can recover from desertification. In a similar way, regenerative technologies and regenerative economies nurture the human emotions with empathy, generosity, sharing and solidarity, so that human relationships can grow healthy and society can develop towards peace, equality and prosperity for all, in a balanced relationship with nature. Yet, the current situation is not optimistic: wars, genocides, hunger, extreme poverty, climatic disasters, loss of biodiversity, behavioural diseases, forced migrations, racism, gender violence and so on provide a series of challenges for humankind. Western civilization is reaching its own limits and it is facing the consequences of sustained exponential growth.Greed and power are the driving forces of the world. Each civilization has educated its youngsters to the needs of its means of living. Societies of hunter-gatherers train their children to learn what plants are edible. Craftsmen have apprentices that learn their craft. Our current civilization educates engineers and economists to develop the enterprises and technologies that serve the purposes of the rich and the powerful. The time has come to create the foundations of the next civilization, that centres the education on the global needs of humankind, and the true necessities of the people and the environment. Our current education system is organised from disciplines to applications. Yet, the education system we promote should be centred on meaningful challenges, and find all available means to solve them. Empathy, generosity, solidarity, cooperation, and sharing are the values that should replace our current profit-based behaviour. Thus, maybe the time has come to transform our concept of an engineer from someone who is able to devise new technologies, to someone who is able to solve problems even without technologies, if none are required. This paper is intended as a side documentation for a workshop. Our goal, then, is not to provide solutions, but to set up provoking questions and situations, hoping for a fruitful discussion.

**Keywords**: The risks of technology; Exponential Growth; Global challenges; Human-scale necessities; Regenerative Technologies; Necessity-Centred Education.

*The shortest path from barbarism to decadence is civilization*
From the film *L'aventure c'est l'aventure*

*Life does not have a meaning. The meaning* is *life*
Mata Amritanandamayi

*La vie est belle, le monde est pourri*
Manu Chao

## 1 Introduction

Every society educates their young people to be prepared for those activities that the society requires for its proper development. Thus, hunter-gatherer societies teach the youngsters to know which plants are edible and which are not, and how to hunt. And craftsmen have apprentices to carry out and learn their craft.

Our current society has reached a high level of complexity and the young people have a wide range of activities to choose from, ranging from the agricultural sector, to industry, services and cultural activities. Yet society is organised around the marketplace, and science, technology and economics play a central role in the development of the economy. Power and money rule the world.

In the  last 200 years, our civilization is undergoing an unprecedented expansion that reaches all aspects of life. Population growth, continued growth of world GDP, economic inequality, technological innovation, exploitation and depletion of natural resources, exploitation of data and information, urbanisation in ever larger cities, pollution, environmental degradation, and so on.

As engineers we know that unlimited exponential growth is unfeasible, yet the economic system requires sustained growth. In spite of all warnings (Club de Roma, 1972), our society is not able to slow down, and there are clear symptoms that we are reaching the limits of the planet (Meadows et al, 2004; Dixon-Declève et al. 2022).

Sadly, our society has yet proven unable to solve the above issues, together with the issues of coexistence among fellow individuals and with the rest of nature. Wars, genocides, racism, gender violence, inequality, poverty, starvation, migrations, climate change, loss of biodiversity, desertisation, and so on fill the pages of our newspapers every day.

The economy is centred in consumerism and profit making, rather than focusing on the needs of the people and the environment. The activities of society are ever more complex, and only a few of them are related to subsistence tasks.

This paper focuses on the causes of the current crises, the challenges that must be faced, and the approach that must be taken for a new civilization to emerge. And therefore, we focus on what education should be *in the future* to reach peace, equality and prosperity for all.

This paper has been written from the stand-point of pacifism, and sustainability: we claim that a resource or a consumption habit is *sustainable* if it is not harmful to oneself, the others or the environment, and it is available to all, now and for the next 7 generations.

In section 2 we focus on the role of technology in the current crises, and section 3 points out how money is the main cause and the tool for inequality and exponential growth. Section  4 is a sample of the challenges of our civilization and section 5 is a description of human scale necessities, as opposed to consumerism. Section 6 proposes the use of natural economies and regenerative technologies for subsistence and satisfaction of the human needs. And section 7 suggests some ideas on what education in this utopian future would be.

This paper is intended as documentation for a workshop. Participants to the workshop will be organised in teams, and each team will receive a deck of cards with 6 suits. Each suit corresponds to one of the mentioned subjects:

- The power and risks of technology (section 2).
- Money and economic growth (section 3).
- Challenges of our society (section 4).
- Human scale necessities (section 5).
- Natural economy and regenerative technologies (section 6).
- Human scale, necessity-centred education in the future (section 7).

For each suit, each card contains a brief question or statement related to the corresponding subject. Each team will choose 5 cards from each suit, and will prepare a poster with their reflection on how education should be in the future. The workshop will then proceed with a short presentation of the posters and a general discussion.

Rather than expanding each subject, which would take a lot of writing space, the rest of this paper is an inventory of the questions and statements that will be found on the cards during the workshop.

Of course, the goal of this paper is not to provide solutions, which we do not pretend to have, but to think out of the box and foster reflection and discussion. Hopefully, the workshop will elicit potential paths of regeneration.

## 2 The Power and Risks of Technology

This section poses the question of the risks of technology. It might even be that technology in itself, as a human activity, *is* the risk. Maybe there is no way to prevent the unexpected consequences of technology, its transformation power, the leap in productivity, its misuses and its spread. In an ever faster pace, technology has transformed the planet into its current predicament,

Not to mention the crucial role of technology in warfare.

- What happened to the Tuareg culture when they first saw the 4-wheel-drives of the Paris-Dakar Rally?
- Imagine that you have just invented The Drone. How can you prevent its use for surveillance or warfaring purposes?
- People say that the tools are neutral, that the *use* of the tool is what is under question. But what is the neutrality of a war missile?
- Inventions have multiple applications. Some are good and some are not. But you can be confident that, if malicious applications are possible, somebody will put them into use.
- Technology is an amplifier. The capacity of harm of a hammer is much less than that of an atomic bomb.
- The technology of today makes the magic of the past become true (and the dreams of science fiction writers). Beware what you dream of.
- What is at stake if a nuclear plant leaks? Why should we take the risk?
- Once you try them, it is practically impossible to renounce the commodities of technology.
- Who could expect that fertilisers and pesticides would poison the aquifers?
- A substantial part of technology is of military origin, or funded by the "defence" departments. Companies, afterwards, take advantage of the research.
- Of all possible technological developments, only those that make profit thrive.
- Most technologies are out of reach for the majority and, therefore, they are not sustainable.
- Many technologies overexploit and deplete the resources they use.
- The word *progress* is a tricky word, because it is supposed to be "good". But it often hides unexpected consequences (Wessels, 2023).
- If you never left your city, you don't know what the stars look like. Or where the milk comes from.
- Technology-based productivity increases exponentially. Those who start later will become dependent and will never catch up.
- Our current education and research system is centred around disciplines and crafts. New devices are first invented and then marketised, even if they are not necessary.
- Thanks to technology, the standard of living has risen… for a third of the world population.

## 3 Money and Economic Growth

The goal of our economy is sustained exponential growth (percentual growth of GDP). Moreover, the growth of the economy is actually a *requirement* for the economic system to survive. Yet, resources are limited and, therefore, exponential growth is not sustainable.

Money, the wealth concentration tool, is the technology that makes this economic system possible.

The western society (in a broad sense) is facing an unprecedented crisis.

- Money is the technology of trade (Ferguson, 2009; Wild L, 2011).

- Money is an intermediary between human activity and consumption. Rather than producing what we need, we work for money and buy the goods we use.
- Our economic system fosters inequality (Piketty, 2015)
- The values of patriarchy are power and money.
- Money and trade foster individualism and selfishness.
- Those with no income starve. Those with a low income hardly survive. Those with a medium income, consume commodities. Those with a large income save and buy luxury assets… Those with obscene amounts of income rule the world.
- Publicity promises what the majority cannot attain.
- Banks provide… at an interest rate. Or they keep the collateral.
- The rewards of capital are exponential (percentage). The rewards of labour are linear. Resources are not rewarded, but exploited.
- The benefits of trade are larger for the party with absolute advantage, and trade perpetuates the inequality. Ricardo's model legitimates the exploitation of the poor. Let Tom Bradley mown its own grass!
- Market equilibrium is the mechanism by which to tell those who can afford a product from those who cannot. Those with a larger budget get the bigger surplus.
- Picture a simple economic model with families on one side and companies on the other. Families buy food and sell labour. Companies buy labour and sell food. If companies make a profit, what happens to the families?
- Micro-credits monetize otherwise self-sufficient subsistence economies. They at the base of an ever growing pyramidal scam.
- Adam Smith said that, even if the parties in the market look for the maximisation of their profit, society as a whole is better off. Is this not a paradox?
- Big companies earn big profits by cheating very little from a lot of customers. A thousand slightly unfair trades is a big scam.
- Loaning is an explicit form of usury.
- Most of the money in circulation is created by the banks by lending money. At the end of the day, when the loan is paid back, banks still reclaim an interest. But the money for those interests was never created (Duran, 2009).
- Banks make loans today in order to create money for the reimbursement of yesterday's interest (exponential growth).
- If all companies are expected to make profit, where does the money come from?
- The main misuse of money is called speculation.
- Money is not at reach for everyone. Therefore, money is *not* a sustainable good.
- Money makes money, only if money is scarce.
- Inequality grows both during economic expansions and during economic recessions.
- Since banks decide who they lend money to, they have the power to determine which projects can be carried out and which cannot.
- The financial system is a pyramidal scam.
- Who has the money sets the price. The marketplace is dominated by monopolies and monopsonies.
- The market cannot deal with unemployment, even when there remain a lot of things to do.
- Poorly paid labour is today's slavery.
- Investors are said to put their wealth at risk. But what is the legitimacy of their wealth, in the first place?
- The price of goods does not depend on their intrinsic value, or the necessities they satisfy. The price is set to maximise profit.
- The marketplace favours individualism, egotism, and massive consumption.
- There are goods and commodities fit for every income level: 1, 10, 100, 1000, 10.000 … 1.000.000.000. Marketing offers each of us commodities for the next level, leading to frustration or indebtment.
- Leisure is a commodity.
- Migration is the consequence of economic inequalities.
- The current economic model relies on the assumption of unlimited growth, which is not sustainable.

- Economic growth is a *requirement* for the economic system to prevail.
- Money is a zero sum system. If someone takes a profit, someone else must take a loss.
- If every business is supposed to make profit, then there need to be more businesses to generate the money (exponential growth).
- Money is a cultural abstraction. And a harmful one.
- Debt is a slavery system (Graeber, 2012).
- The main role of the state is to protect the right of property. But property is concentrated in the hands of a few.
- In the beginning there was the land and the people. Then, a few of them claimed ownership over it.

# 4 Challenges of our Society

Our society has reached the limits of the planet in its exploitation of resources, and half its population is currently living in poverty. Genderism, ageism, racism and other isms are present everywhere. Nature is being polluted and depleted. Many species are disappearing, War and violence are commonplace.

The future of humankind depends on our ability to solve these challenges.

- What technologies are required to achieve peace?
- Suggest three different ways to prevent the accumulation of wealth.
- Genocides are a recurrent situation in history.
- Our civilization is undergoing an explosion, and reaching the limits (Thuillier, 1995; Sempere, 2023)
- More than half the world population lives in poverty.
- In our society, our lifestyle is stressful and leads to mental diseases.
- Everyone should have access to common resources such as unpolluted air, water, food, accommodation, etc.
- Population is overconcentrated in big cities.
- Most of us live alienated from nature.
- Many countries, formerly exploited, are currently burdened by public debt (Auditoria Ciutadana, 2013).
- An unprecedented amount of species are under the risk of extinction.
- Many regions live in misery as a result of western colonisation and exploitation.
- People in poor regions have no other alternative than migration.
- Migrants are refused their right to live at home (misery), and elsewhere (racism).
- Big cities are full of homeless people.
- The values of care taking and reproduction are underestimated.
- We live under all sorts of violence, especially gender violence.
- The leftovers of our industrial society are causing climate change, with the risk of major climate disasters.
- Heavy fertilisation and pesticides are causing desertification of the land.
- Monoculture and the hijacking of seeds prevent traditional subsistence agriculture (Shiva, 1999).
- Deforestation harms the lungs of the planet.
- We live in a world of selfishness and individualistic relationships.
- All species deserve respect.
- Natural resources are being depleted because of the consumption habits of the wealthy.
- The western ways of living produce pollution in land, sea and air. Even the stratosphere is full of satellite garbage.
- Films and media promote violence.
- Our economic system has no solutions for unemployment, even when there is work to be done.
- Many occupations are unproductive and frustrating.

# 5 Human-scale Necessities

This section is based primarily on the work of Max-Neef (1986), that distinguishes between necessities, satisfiers and goods.

According to Max-Neef, human necessities are subsistence, protection, affection, understanding, participation, recreation, creation, identity, freedom and transcendence. Satisfiers are the means by which necessities are realised, and goods are their practical counterpart (artefacts, technologies and services).

- Accommodation is a satisfier for the need of subsistence. There exist many kinds of accommodation. There is no need for luxury (other than ostentation).
- You can realise your need for recreation by singing a song or buying a yacht. One of them does not require money.
- Poverty is not really the lack of money, but the inability to satisfy some of the needs.
- Breastfeeding is a synergetic satisfier. It realises several needs: survival, affection, protection, identity etc, in both the mother and the child.
- Drinking is a satisfier for the need of subsistence: many commercial drinks, rather than satisfy the thirst, actually harm the health of the drinker.
- The term necessity is usually understood as the lack of something. But most human-scale necessities are actually potentiated when they are satisfied.
- The ecological farmer Fukuoka said that he never worked. He just wandered around his garden and did what he saw that was necessary (Korn, 2017).
- When artefacts become an end in themselves, consumers become dependent on them.
- The sense of belonging to a group is a satisfier of the necessities of participation and identity.
- Associations and neighbourhoods satisfy the necessity of participation, and enhance protection, affection, identity and freedom.
- Mindful meditation is a satisfier for the need of transcendence.
- Books are artefacts that can satisfy the needs of understanding and leisure.
- Autonomy and self-esteem satisfy the need for liberty.
- All necessities are equally important for human-scale development.
- Bioconstruction is a realisation of sustainable accommodation.
- Music, arts and theatre satisfy the needs of understanding, creation and participation.

# 6 Natural Economy and Regenerative Technologies

The principle of regenerative agriculture is to focus on the soil and nurture it with microorganisms, minerals and organic matter, so that plants can grow healthy and the land can recover from desertification. Apart from capturing water in the soil, like a sponge.

In a similar way, regenerative technologies and regenerative economies (Col·lectiu Mostassa, 2017) nurture the human emotions with empathy, generosity, sharing and solidarity, so that human relationships can grow healthy and society can develop towards peace, equality and prosperity for all, in a balanced relationship with nature.

- Reclaim the commons! (Subirats, 2016; Tirole, 2016; Shiva, 2020)
- The alternative to money is not bartering, but sharing.
- Sharing promotes emotions of altruism, solidarity, generosity, belonging and socialising.
- Degrowth is a must (Kallis, 2018).
- You can be poor in terms of money, but still you can be prosperous if you can realise your necessities (Shiva, 1988).
- Downshifting is not having less, but making a better use of what you have (Linz et al, 2007)
- In a world with no trade there is room for creativity.

- In a world with no money many occupations would become unnecessary. Imagine the amount of free workforce.
- Non-commercial satisfaction of our necessities is a means of self-fulfilment.
- Care taking should prevail over patriarchy values.
- Good habits regenerate health.
- If we focus on our necessities, we will find the proper and simplest solutions.
- The realisation of most necessities does not require "hard" technologies.
- Growing local gardens would prevent starvation when the crisis of the economic system arrives. Growing gardens for survival would accelerate the fall of the economic system. Win-win. Let's sow tomatoes!
- Seed balls is a technique for preventing desertisation (Fukuoka, 2009; Fukuoka, 2013).
- Regenerative agriculture focuses on nurturing the soil (Schreefel et al, 2020; Wikipedia).
- Regenerative agriculture does not require big machinery.
- Sharing and regenerative technologies nurture the human soul.
- A new civilization can grow if we are able to dewesternise our societies.
- A requirement for a technology to be regenerative is that it has no potential misuses.
- Bioconstruction refers to the use of environmentally friendly materials and techniques in building and architecture.
- Regenerative technologies do not pollute the environment, but they regenerate it.
- It is better to prevent the causes than to mend the consequences.
- Polluting less is still polluting. We need cleansing solutions.
- Culture does not need to be a market commodity. The arts are a satisfier for the need of creation.
- Small communities provide face-to-face communication and require less infrastructure.
- Regenerative technologies seek solutions both in traditional knowledge and in creativity.
- Rather than inventing and selling new commodities, engineering should focus on the simplest solutions to human-scale necessities.
- In a necessity-centred society, many disciplines will no longer be required. Imagine the amount of workforce that would be liberated.
- It is hard to think that our western civilization will be able to solve the challenges it has created. The hope is on indigenous, money free societies (Martinez-Alier, 2011; Tirole, 2018).
- When the collapse arrives (and it is not far away) only those with locally subsistence resources will thrive.
- Regenerative economy uses money just once. It uses money in the beginning to provide for the tools and external materials, then it continually produces food, thanks to the land that provides for free.
- Regenerative economy transforms money for food, from the bottom of the pyramid to the top.
- Regenerative economy is based on sharing, rather than money transactions or bartering.
- In regenerative accounting, rather than a number in a sheet (the balance of money in their account), each person will take note of their necessities, an explanation of the things that they have done or given to others, and an explanation of the favours and goods they have received. Those accounts should be qualitative, avoiding quantification.

# 7 Human-scale, necessity-centred, education in the future

Each civilization has educated its youngsters to the needs of its means of living. Societies of hunter-gatherers train their children to learn what plants are edible. Craftsmen have apprentices that learn their craft. Our current civilization educates engineers and economists to develop weapons, or ever new commodities to furnish the military and the marketplace, enriching a few.

The time has come to create the foundations of the next civilization, that centres the education on the global needs of humankind, and the true necessities of the people and the environment. Thus, maybe the time has come to transform our concept of an engineer from someone who is able to devise new technologies, to someone who is able to solve problems even without technologies, if none are required.

If we have to build bridges between society and learning in the future, we must rethink our whole education system.

In such an utopian society:

- Future engineers would know what is at stake.
- Education and research would be organised around necessities and challenges, in order to provide sustainable solutions.
- Every young person would have to learn and practice subsistence crafts.
- Young people would have to learn how to grow food and, eventually, raise cattle in a regenerative way.
- Young people would learn the procedures of regenerative economies, and regenerative accounting.
- Engineering would be the ability to creatively solve problems (wit) using a wide range of knowledge and skills.
- Learning traditional crafts would be necessary for necessities such as clothing or building furniture.
- From the need to the solution, rather than from the invention to its economically feasible application.
- Education would be student-centred, with the students developing their own learning path.
- Children and youngsters would learn the satisfactors for their human-scale needs.
- Children and young people would be grown with the values of empathy, solidarity and love.
- Children should be able to freely develop their natural potential (Wild R, 2002).
- Schools and learning institutions, when necessary, would use practical workshops rather than frontal lectures.
- Education would incorporate aspects such as emotional intelligence, interpersonal skills, creativity, critical thinking, and self-awareness.
- Children and young people would learn the habits of a healthy means of living.
- Education in health would prevent diseases.
- A healthy sex education would prevent many misbehaviours.
- Education would value collaboration, empathy, and respect, fostering a sense of belonging and community among students and educators alike.
- Educators would be facilitators of the apprentice's learning process.
- Young people would learn by actually carrying out the necessary activities for their fulfilment.

# 8 Recapitulation

This paper focused on the education of the *next* civilization. Our current western society, ruled by the greed for money and power, has proved incapable of solving the challenges and problems that the exploitation of people and resources has generated. Technology has changed the world in unexpected and unsustainable ways. Money has become a wealth concentration machine, and the natural needs of human beings have been coopted by technologies and artefacts that alienate us from ourselves and the environment, and contribute to inequality and frustration. Wars, starvation, climate change.. these are the actual challenges that need to be urgently addressed by means of regenerative and sustainable technologies.

In this utopian future, education would be centred in the realisation of human-scale necessities.

*You may say that I am a dreamer, but I am not the only one*
John Lennon, *Imagine*

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# PAEE/ALE’2024 Full Papers

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# Interdisciplinary teaching of ethics and translation to university students to provide social service to children with disabilities

Gerardo S. González Lara[1], Martha Catalina del Angel Castillo[2]

[1] Department of Humanistic Studies, School of Humanities and Education, Campus Monterrey, Tecnologico de Monterrey, Mexico
[2] Department of Modern Languages, School of Humanities and Education, Campus Monterrey, Tecnologico de Monterrey, Mexico

Email: gsgonzal@tec.mx, marthadelangel@tec.mx

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**Abstract**

Despite the advance in technology for educational purposes, there is still a need for students to have a real-life experience outside the classroom. This leads professors to look for associations or companies that need the voluntary work of students from different fields. Designing a course with a social service component is a complex task because of the administrative processes within the institution and the academic training that professors need to acquire in order to design the content and activities of their courses. This paper describes the social service experience of two professors conducting interdisciplinary teaching of ethics and translation at a university located in northern Mexico. Thirteen students majoring in Music Production participated in a special semester called Semestre i (Semester i) designed by this university to engage students in Experiential Learning. In this project, students provided community service to a local association devoted to improving the quality of life of children with cerebral paralysis and their families through a comprehensive care model that promotes their maximum level of autonomy and inclusion in their environment. The association required the translation of an American manual of instruments used for various motor therapies to improve the speech, feeding, and sensitivity of children with disabilities. Therefore, professors taught students the principles of ethics and basic translation strategies through tailor-made activities so that they were able to provide this social service. The results showed that doctors, therapists, parents, and children were able to understand and use these instruments properly. Besides conducting social service, students committed themselves to the project cultivating empathy and embracing inclusion, and the Association and the University integrated relationship-building into more social service projects.

**Keywords**: Ethics, social service, language, interdisciplinarity, innovation.

## 1 Introduction

A traditional translation course allows students to practice translating material from various disciplines at their universities. These practices range from isolated sentences to books and magazines that pose challenges for this skill and with the help of the teacher, students can create different versions for the sake of a natural and faithful translation of the original text; very similar to what (Álvarez, 2012) calls a purely linguistic perspective; that is to say, the translation class was a way to learn the language through selections of texts with translations with comments on the lexicon, grammar or style. It was customary to read, translate, review, and correct the text in class, considering what was learned and the professor's feedback. Students tend to lose their motivation because this method becomes predictable and routinary to the point that if there happens to be confusion, it is corrected with no further consequences because the audience is represented only by the classmates and the teacher, in other words, the final version does not go outside the classroom.

Two university professors conducted interdisciplinary teaching: one professor of ethics and one professor of English-Spanish translation. The project took place at a university in northern Mexico with undergraduate students majoring in Music Production. Although following the interdisciplinary approach may have disadvantages such as integration confusion and time-consuming curriculum preparation, the advantages are enriching because it expands students' understanding and achievement between disciplines, enhancing communication skills (Jones, 2010).

Thirteen students majoring in Music Production participated in a special semester called Semestre i (Semester i) which was designed to give them the opportunity to have a real-life experience in their community so that their projects had a real ´customer´. For this university, Semestre i refers to a program in which undergraduate students strengthen and develop their skills through experiential learning experiences to face challenges together with companies and organizations throughout an academic semester (Tecnológico de Monterrey, 2017).

## 2 Experiential Learning Model

It is important to notice that Experiential Learning is a model that allows students to build their own perspectives on learning. In the words of (Chan, 2022): "A valuable experiential learning curriculum allows students to reflect, relearn, react, reinvent, reform and reapply their learning". Students who enrolled in this special semester participated as their interests were highly likely to align with the project's objectives which were meant to answer to the real-life needs of a community. Like most non-profit associations whose resources depend on donations and voluntary work, the ethical and translation skills students provided were welcome by the association.

The primary requirement to enrol in this project was for students to have already achieved a B2 level in accordance with the Common European Framework of Reference (Cambridge University & Assessment, 2023). It may appear odd that the measurement comes from a European, rather than an American institution. However, the Common European Framework is widely used because it covers other languages, making it easier for the university to contrast and compare scores across all their language classes, not just English. Nevertheless, it is also commonplace to write an exam in the United States or Canada and then convert the result to the Common European Framework. This way of measurement may also encourage applications in other languages, eventually.

The reason to require this level is rooted in the goal that students are advanced and independent enough to be able to understand the main ideas of the provided materials in the specific context they may find themselves in. It is important to remember that most students will need to step out of their comfort zone and delve into an area of knowledge to which they most likely have had little exposure.

Students provided community service to a local association that was founded for prevention, early diagnosis, and comprehensive care for people with cerebral paralysis and related conditions from early childhood in order to improve their opportunities for development and inclusion (Nuevo Amanecer, 2020). The association had just received an American manual with very detailed information about instruments that had been used successfully in the United States to improve the speaking, feeding, and sensitivity of children with disabilities. The personnel of the association were not able to use this information contained in the manual because nobody in their team could read this material written in English nor study the specification of use.

This fact reflects a reality in Mexico, but especially in the northern part of Mexico, where affordable and useful information is often available only in English. This comes from the fact that the USA is very prolific in teaching materials and updated information on the latest trends from different disciplines. The students in question may be very familiar with American documents, whereas the members of the association may not. Considering the topics inserted in Experiential Learning, this paper first presents a brief overview of the origin of social service in universities in the world and in Mexico. Then, it addresses the importance of teaching ethics and translation to carry out this social service with an association that seeks empathy and inclusion for its members. Subsequently, it describes how the classroom activities were linked with the needs of the community and finally, it includes the outcomes encountered by all the actors who lived this social and life-changing experience.

## 2.1 Social service in universities

In addition to teaching 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 career. According to Tecnologico de Monterrey Educational Model, the Social Service promotes the practice of volunteer work from students so that they fulfill their duties with the society as professionals and citizens (Tecnológico de Monterrey, 2016). This model was complemented with the approach of the Service Learning model (Aps) proposed by the Polytechnic University of Valencia (2020) in which they state that: "Service Learning is a teaching methodology that allows the training of students by putting the theoretical contents of the classroom at the service of society" in which, in addition to a methodology, this project requires a work protocol, in which the teachers involved, with the prior authorization of their Department Management, agree with the non-profit entities , public or private, with which they will carry out this didactic experience.

Therefore, in their general university education, students should acquire basic learning outcomes from scientific, technical, as well as ethical, and social points of view. It is important to note that in addition to these lessons, companies also demand academic skills like theoretical and practical training; instrumental abilities such as management skills; more than one language, and a good handle on computing; interpersonal skills like oral and written expression, leadership, teamwork, and cognitive skills like decision-making, critical thinking, daily reasoning, and creativity (García-Ruiz, 2023).

Social service is not something new but has been practiced in universities for a long and stable tradition and is linked to a specific branch of knowledge. An example of this social service practice is the study carried out with undergraduate students at the University of Michigan, USA with the theoretical course called Contemporary Political Issues where students from various disciplines carried out social service with community agencies, such as a nursing home, a crisis management center for women, an ecology development center, as well as counseling for primary and secondary students at risk of dropping out of their studies. The results showed that the students who participated in this project, with the social service component, agreed that volunteer work allowed them to commit themselves and feel useful to help their respective societies (Markus, Howard & King, 1993).

There are many initiatives developed to increase the relationship between universities and industries. In Mexico, the number of people interested in pursuing a major has increased because industrialization in the country has also increased significantly (Sagarra, Mar-Molinero, & Agasisti, 2017). Social service is carried out as part of the student´s integral development at the undergraduate level by doing several activities with organizations and companies. Students are granted hours of social service which are mandatory and thus a requirement for graduation. The number of hours devoted to social service depends on each university.

For instance, a university located in the northern part of Mexico runs a program called Inglés Comunicativo para Normalistas in 2019 (Communicative English for Teacher-Training Students). The purpose of this program is to provide a space for social awareness to university students and to promote participatory and responsible citizenship. The students from different majors who participate in this project are required to have a C1 level of English according to the Common European Framework of Reference for Languages (Cambridge University Press & Assessment, 2023) to be able to provide the opportunity for teacher-training students to develop communication skills by interacting in the English language for three hours on Saturday mornings for 15 weeks in the semester (Departamento de Lenguas Modernas, 2020).

## 2.2 The importance of teaching Ethics and English in universities

It is important to point out that the work of a professor is also to become an adviser who shows confidence and respect towards the different possibilities for professional development of every student so he/she can achieve integral professional training (Ayala, 2002). This ethical reflection is essential for educational institutions and for the current university student considering the immersion of technology and the scientific world in human actions, which tend to minimize the reflection of a humanistic nature; that is to say, ethics nowadays is very necessary but weak. That is why there must be instruments that are as clear as possible through which ethical values are understood and internalized throughout the student's university life (Etxeberría, 2002)

Thus, teaching ethics and translation to students at advanced levels of the English language is one key skill for cross-border life in northern Mexico. For instance, the university in question was modeled after MIT and has regular classes in English to both propel its local students to seek international exchanges and to enroll as many foreign students as possible to have an exchange in northern Mexico. Because of this, several classes already use textbooks in English, which are not merely translations of Spanish books but are actually textbooks used in other universities around the world. One can see that English continues to be the lingua franca as it is clearly defined by Seidlhofer (2005): "In recent years, the term 'English as a lingua franca' (ELF) has emerged as a way of referring to communication in English between speakers with different first languages."

The students who seek a translation course will most likely feel comfortable enough with the language to also take classes of their major exclusively in English and will then be accustomed to having reading material in English as part of their studies, which will be helpful as will be explained later. If this did not happen in the global world, students would not have access to updated information from different disciplines, nor would they be able to have contact with their international counterparts (Bobanovic & Grzinic, 2011) pointed out:

"In the corporate world, English is the most regularly used language and the knowledge of English has become one of the most important employability skills. Proper English does not only mean the ability to make grammatically correct sentences but also the other related skills for effective communication like presentation skills, convincing and negotiation skills, and interpersonal skills using English."

The American example, among others, has been pursued by universities in Mexico, especially those that aspire to have seamless communication and exchange of students with their American counterparts, even going so far as to arrange their yearly schedules to fit accordingly and improve the most important measures that rating lists look for in order to ultimately compete for the top spots with American universities. Social service may then just be another way in which Mexican universities choose to learn and even improve on the didactic designs as well as on academic and social results of other institutions from other parts of the world.

## 2.3 Linking the needs of the community through classroom activities

It should be noted that the objective of this university course is not at any time to train professional translators (written language) or professional interpreters (spoken language), but rather to confront learners with more complex cognitive processes in specific settings of their communities. Translation and interpretation techniques must be part of the fifth skill methodology (besides reading, listening, writing, and speaking) to master a foreign language and adapt the translated text to the level and specific needs of the students in which the teacher can communicate with the students in their native language. (Naimushin, 2002).

The students could also by inspiration from this activity ultimately pursue to become certified translators in their respective fields or other similar social services. This could especially be the case for those that seek to work for international companies or whose employer will depend on international clients or investors. Other fields that may have a special interest may be lawyers and doctors, as procedures in both countries have a very specialized vocabulary where even translation tools may not be sufficient. Nevertheless, the teaching of translation and interpretation must be clearly distinguished from the traditional proper training of professional translators and interpreters.

Even more so, if students start off with an advanced enough level of English, it will help them understand and handle even technical terms of topic-specific complex texts. Furthermore, it would also come in handy when reading concrete and abstract topics when and if these terms are within their field of specialization. The users should be able to write clear and detailed texts on various topics, as well as to rebut an argument on general topics, indicating the pros and cons of the different points of view (Jiménez, 2011).

The time spent during the project should not be considered a limitation but rather an opportunity to put into practice what students have learned in the course by having real people with the need for a translation to access innovations. The field should be interesting to most students as it is quite a common service, such as dental health, applied to a specific group, children with cerebral paralysis. It is also encouraging that it may not be the primary service that the community thinks about when coming up with ways to help these children. Therefore, it is reasonable to assume that dental services may be easily overlooked in favor of more visible everyday activities.

This is an experience for one semester meeting three hours a week for fifteen weeks which is a useful point of reference to remind students of how much they will apply their knowledge to the project as it will most likely feel like an enormous amount of time. Students had two field trips to the local association: On the first visit to the facilities, both professors introduced students to the doctors, therapists, and some children, that is to say, the actual readers of their translation work. Students also had the opportunity to ask questions about the courses taught by the association, the profiles of the users, the limitations that children with cerebral paralysis encounter to be fed, swallowing their food, and the like. On this first immersion, students were able to see the needs of the association and how relevant this translation was for the health and welfare of children.

On their second visit, students participated in a social event organized by the association where children, personnel, and families from the association showed their academic work. This was an opportunity for students to feel part of the association which supports parents and their children to improve their quality of life together including volunteers and full-time personnel. After these visits, students were able to reinforce the need to assimilate the values of empathy and solidarity to perform this social service for a real social cause.

It was also refreshing to notice that there have been similar experiences in other fields. Although it should be noted that they have had limited exposure to actual social work. They have had great student outcomes though, so their example was considered a starting point for the project at hand. Even limited experience in a community service laboratory may change the way students' way of thinking regarding obligations and opportunities for social service and the people who need this service as well as a way of getting new relationships with the community to encourage volunteer work (Giles, Dwight & King, 1994).

This social service allowed big challenges in the content and didactics of ethics and translation courses. The activities for both courses were tailor-made. Some activities were designed to be done by students individually and some others to be done collaboratively. To teach ethical principles, the following is an example of one activity based on the classic short story called "The Pied Piper of Hamelin". After reading it, the student responded to questions to reflect on the ethical principles portrayed in the story. These are some of the open questions assigned for this activity and how one of the students replied:

Question: What initial values inspired the Pied Piper?

Student´s response: Kindness, solidarity, empathy.

Question: Alluding to the Pied Piper of Hamelin as a metaphor, as a student majoring in Music Production, what values do you consider should always be practiced in your profession?

Students response: Those that the Pied Piper of Hamelin exhibited before being deceived as kindness and solidarity. Always seek that our work is to help others. In addition to this, always practice frankness to prevent us from being deceived, but also fidelity to our values so as not to forget them and then act wrongly.

Through this activity, one can see that students were able to identify values and how ethical and moral values are assimilated into their life and later as professionals. Empathy was one of the key values shown in the story so that they could put it into practice in their social service. Solidarity was another key value practiced in the social service for the association. A person that practices solidarity supports others in need. Philosophical ethics is inserted in the human condition and present in our daily life and impacts decision-making, reflecting a moral fact and awareness that should have been behind the person who made a certain decision. Thus, ethics is especially accessible to anyone because the language used is the so-called "ordinary language" spoken by ordinary citizens and not a formalized language such as logic or mathematics (Cortina & Connil, 2000).

As to the translation activities, the material in the manual was divided into six sections consisting of approximately 1,000 words in English depending on the number of images per page. Therefore, the class was divided into six teams so that students could work collaboratively on the section assigned by the professor. Previously, students were also trained with exercises about general topics in the classroom to later apply them to the project through translation strategies. For instance, the description of the products had to be precise for medical personnel and simple at the same time because parents and children would also read the material to select a product that matched their dental needs. One example of this type of adaptation was the following paragraph taken from the original version in the American Manual (Lowsky, 2018):

"ARK's DINO-BITE ™. This "roarsome" T-Rex design is sure to be a hit with dinosaur fans. At 1.5 X 2.5" and just under 1/2" thick, this is a pretty ´beefy´ chew pendant (and the longest-lasting necklace option for avid chewing). Great for chewing with the pre-molars and/or front teeth".

While the translated version was also targeted at any reader who wanted to select an instrument, shapes and measures were really important. For example, the dinosaur shape and the noises it makes made it attractive to children. The noises had to be onomatopoeic words and the measures had to be converted into centimeters. This was the translated version presented by one of the teams:

Dino-Bite de ARK ™ [¡Este diseño de T-Rex hará rugir de alegría a los dino- fanáticos!] A los fanáticos de dinosaurios les encantará este espectacular [[Roartástico]] diseño de T-Rex. Con un tamaño de 3.8 x 6.3 cm y alrededor de 1.3 cm de espesor, este colgante es lo suficientemente "robusto" (Y la opción más duradera para uso constante). Ideal para morderse con premolares y/o dientes frontales.

In this translation, one can see that the adaptation from the source text to best suit the readers of this description of the instruments was essential. The adaptation has to do with cultural differences in the source language, English, and Spanish, as the target language. The culture of the United States and Mexico was reflected appropriately (Del Angel, 2019)

The students in question will no doubt have experience with online translator tools, as they are widely used by the public. Tools that translate individual words or a full text are commonly used, however, there are specialized tools that even professional translators use on a daily basis and that need some knowledge in order to get the most out of them. This is where the supervision of the professor has been key to have achieved a faithful and natural translation.

Technology has made various tools available to translators that allow them to carry out their work more efficiently and accurately. When translators work on a computer, it paves the way to have access to essential tools such as general, terminological, and encyclopedic dictionaries. This is called assisted translation which makes all the resources that may come in handy available automatically to translators (Oliver, 2016). There are cutting-edge technological tools to streamline the translation process from one language to another. However, it is necessary to make a distinction between Computer-Assisted Translation (CAT) and Machine Translation (MT). TAO and TA are two processes that share a common objective: producing a text in one language that conveys the same message in another. Needless to say, they are two different processes in which human intervention makes a difference; that is, in the first, CAT, it is the translator who translates the text with the help of tools, and in the second, MT, there is no human intervention since the text is produced entirely by a machine. (Chueco, 2017).

The content of the class contained several strategies to be applied and students were not left alone in the process to test their newly acquired skills. Also, as a way to have a self-auditing process, students were asked to show their version to a native speaker of Spanish so that he/she could point out what was not clearly stated. This should be a humbling experience for the students as understanding the language does not automatically enable you to express it clearly and to the point.

As to the step-by-step evaluation of their translated version besides the feedback and changes suggested by the professor, students had to reflect on their own performance in order to ponder on their successes and mistakes and to also use their stronger areas towards a better performance on their weaker areas. These specific elements of self-understanding, such as goals, values, and obsessions promote action and self-regulation (Vallacher, Nowak, Froehlich & Rockloff, 2002).

Students also reflected on their collaborative work by considering not only their participation in the translation process itself, but also the organization of the team of students, the planning required to meet the deadlines agreed upon in the team, attending meetings to check the overall progress, and supporting their peers by identifying who's best suited for each part of the process with a self-assessment and co-assessment instrument designed by teachers specifically for this project. This is also an example of collaborative work in a didactic process: "Work, collaborative or otherwise, is best understood in terms of the context in which people are working, and its influence and constraints on structures and processes, performance and success." (Patel, Pettitt & Wilson, 2012).

Furthermore, the fact that the professor revised the final version and submitted it to the association validated the whole process and provided confidence that the work had been done accurately. Students reflected on the process about acknowledge and empathy with people with disabilities and the possibilities that the environment offers to support their opportunities and the student acts as a dynamic performer to achieve these efforts towards the community.

## 3 Conclusion

The purpose of this paper was to share how professors can prepare students to participate in social service through Experiential Learning. Although the exercises solved in the class were challenging for students, there was no real social cause behind them before this project came along. The outcomes that resulted from this project were very enriching for each of the actors participating in this project:

The professors were able to encounter the challenge of tailor-made design for this specific project and despite the possible disadvantages of interdisciplinary teaching stated by Jones, 2010 such as integration confusion, it was possible for the ethics professor and the translator professor to complement their content and activities because students needed to reflect on empathy and inclusion before they were able to visit the association or even read the manual.

The university in question, granted 100 hours of social work to students for supporting the association in this regard. It should be noted that students need a total of 480 hours of social service as a requirement for graduation and that the students who were registered in this program were mainly freshmen, so it became very attractive to have 100 hours of social service during the first semester of their major.

The association because they received their Spanish translation of the 40-page American manual so that doctors were able to prescribe and describe thoroughly more than 50 varied types of ARK instruments available for different motor therapies for children with disabilities to improve their speech, feeding, and sensitivity. Both children and their families from the association were able to make a selection of the instrument(s) available to fulfil their needs.

University students, although some typical beginner mistakes were expected, such as coming up with a seemingly coherent but rather unnatural sentence in the final language, they were able to make a translation for a real need of an association and put into practice ethical principles in a real-life context to the point that they were no longer only plastic instruments to bite, but rather, instruments that saved and changed lives.

It may be argued that American and Mexican cultures are quite different. However, northern Mexico does have an ever-present dose of American culture within its borders. So, although the cultural differences have to be taken into account, we should not lose sight of the fact that they may be fewer than what other Latin American countries further south would have. This should be considered if and when this project is replicated somewhere else, maybe even between countries that don't even share a land border. In this sort of symbiosis, all involved participants certainly benefited from sharing knowledge, time, and skills but overall support for the other integrating relationship-building into more social service projects.

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# Innovative Experiences in Engineering Education: Leveraging Continuous Improvement in the Automotive Industry

Soraia Stabach Ribas Ferrari dos Santos[1], Deivison Ferrari dos Santos[2], Eloiza Aparecida Silva Avila De Matos[3]

[1] PhD student in Science and Technology Teaching - Federal Technological University of Paraná.
[2] Undergraduate student in Production Engineering - Centro Universitário Internacional Uninter.
[3] PhD in Education from the Methodist University of Piracicaba, teacher in the Graduate Program in Science and Technology Teaching at UTFPR

Email: soraiasr@hotmail.com, d.ferrari1984@gmail.com, elomatos@utfpr.edu.br

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**Abstract**

This study explores the effective implementation of Problem-Based Learning (PBL) and the Kaizen methodology within the automotive industry, specifically through the development of a wheeled trolley for moving heavy parts. PBL enabled engineering students to apply theoretical knowledge to practical, real-world challenges, fostering innovation and continuous improvement. The Kaizen methodology facilitated a collaborative approach to identify areas for enhancement, devise effective solutions, and assess their impact on production line efficiency and productivity. The introduction of the trolley significantly reduced operational steps, increased productivity, and improved ergonomic conditions, demonstrating the operational and safety benefits. This experience underscores the critical role of innovative practices in engineering education, preparing future professionals to tackle the evolving challenges of the industry.

**Keywords**: Problem-Based Learning; Kaizen; Teaching of Automotive Engineering; Continuous Improvement.

# 1 Introduction

In the automotive industry, where innovation is a constant and the demand for technical and creative skills is essential, engineering education transcends the traditional confines of the classroom. Problem-Based Learning (PBL) emerges as a pioneering methodology, empowering future professionals not only with theoretical knowledge, but with the ability to face real challenges in the sector. (Ribeiro, 2008)

In this case study, PBL is adopted as a catalyst for continuous improvement in the automotive industry, aligning with the essence of Kaizen, a Japanese philosophy that advocates continuous improvement. The focus is to create a Dolly Wheel, a crucial piece of equipment in the optimization of the assembly line. By integrating PBL into engineering education, it not only promotes the development of practical skills but also creates a strong bridge between theory and practice. (Araújo, 2011).

PBL not only enriches the educational journey of students but also fosters the growth of teachers by encouraging collaboration and knowledge exchange in a dynamic environment. Recognized for its effectiveness in several areas of knowledge, PBL plays a key role in preparing the engineers of the future for the complex and emerging challenges of the automotive industry. The integration of active methodologies, such as PBL, in higher education has been seen as fundamental for the development of students' critical thinking (Rezende and Silva-Salse, 2021)

As the automotive industry moves towards sustainable mobility (Lara and Marx, 2015), the application of PBL in engineering education becomes even more crucial. Innovative experiences in teaching not only empower students with practical skills, but also stimulate creativity and stimulate complex problem-solving, preparing them to thrive in a context of constant change in professional life.

## 2 Method

The present work is characterized as a case study applied to an automaker based in Curitiba that stands out in the manufacture and assembly of heavy vehicles. This study was carried out in two distinct phases: an extensive review of the literature related to the topics in question and a field investigation in the process/area: Preparation and sequencing of axles of heavy vehicles. The last stage was carried out through case studies, a method considered appropriate by Yin (2005) to explore contemporary phenomena in their real contexts, using various sources of evidence, such as interviews, direct observations and document analysis. The author highlights the ability to use multiple sources of evidence as one of the distinguishing features of case study-based research.

### 2.1 Case Study: Stages of PBL

After the evaluation and approval of the wheeled trolley, the project is considered to be successfully completed. Presentation of Results: The team presents the results of the project, including the benefits and impacts on the productivity and safety of the production line. A final review of the project is conducted, documenting the results achieved, lessons learned, and recommendations for future improvements.

Table 1. Stages of the Case Study

| Stage | Description |
|---|---|
| 1 | The employee, a student of production engineering, identifies a problem on the production line: difficulty in moving heavy parts. This can include data analysis, workplace observations, and feedback from colleagues. |
| 2 | The improvement proposal is registered in the factory's internal program for analysis and approval. At this stage, the employee formally presents the proposal, describing the problem, possible solutions, and expected benefits. |
| 3 | The project team initiates the Kaizen process by documenting the current state of the process with flowcharts or visual representations. Detailed reviews of the existing process are conducted to identify areas of improvement and understand the underlying causes of the problem. |
| 4 | The team proposes an innovative solution, such as the development of a prototype wheeled trolley to facilitate the movement of the parts. The proposed solutions are discussed and evaluated for technical and economic feasibility. |
| 5 | The team seeks authorization from the logistics engineering department for the implementation of the solution. Formal approval from the logistics team is requested, ensuring that the proposed solution is compatible with existing processes and operational requirements. |
| 6 | The team prepares a budget and submits it to the cost center for an evaluation of the benefit/cost ratio. Approval guarantees the start of production. A detailed budget is prepared, including the costs of materials, labor, and any other resources required for the implementation of the solution. |
| 7 | The team forwards the order to the Kaizen workshop, which specializes in the manufacture of the wheeled trolley. After the budget is approved, the order is sent to the workshop responsible for manufacturing the wheeled trolley, where the production process will be started according to the specifications provided by the project team. |
| 8 | The wheeled trolley is manufactured and delivered to the applicant for testing and evaluation. The Kaizen workshop manufactures the trolley according to the specifications provided by the project team and delivers it to the applicant for testing and evaluation under real working conditions. |
| 9 | The applicant tests the wheeled trolley in a variety of situations to verify its feasibility and efficiency. Comprehensive testing is performed to ensure that the cart meets operational requirements and provides significant improvements over the previous method of moving parts. |
| 10 | After the evaluation and approval of the wheeled trolley, the project is considered to be successfully completed. Presentation of Results: The team presents the results of the project, including the benefits and impacts on the productivity and safety of the production line. A final review of the project is conducted, documenting the results achieved, lessons learned, and recommendations for future improvements. |

# 3 Findings

After the demand was identified, the problem was promptly registered in the company's continuous improvement system. This record marks the beginning of the improvement process, giving formality and priority to the identified theme. The development of Kaizen, a method aimed at continuous improvement, begins. This process involves the collaboration of multidisciplinary teams, which focus on the detailed analysis of the problem, the identification of its root causes, and the proposition of effective solutions to mitigate the excess movement during the sequencing and preparation of the axes in the production line.

To corroborate and deepen the analysis of the waste generated by unnecessary movements, a spaghetti chart was prepared, which is of great importance for reducing the movement time and the need for movement (Coutinho, 2020). This graphic was created with the objective of visually mapping the flow of movement of the elements used during the process of sequencing and preparation of the axes in the production line, as shown in figure 1.

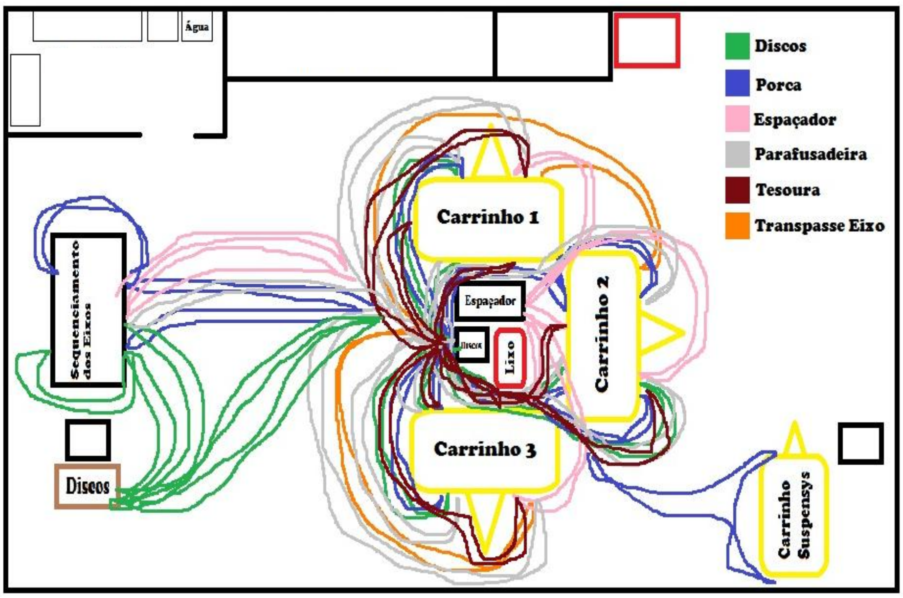

Figure 1. Spaghetti Chart Process Mapping Image

This analysis was based on a three-vehicle manufacturing round, in which the operator's steps were recorded through a counting application, totaling 899 steps, between sequencing and axle preparation. This visual representation provided valuable insights by identifying the points with the most unnecessary movement, highlighting critical areas that needed intervention to improve the process. This step was essential to identify potential solutions and consolidate the need to implement substantial improvements in the operational flow.

Subsequently, the Ishikawa Diagram was elaborated, as illustrated in Figure 2. Also known as a Cause and Effect Diagram or Fishbone Diagram, this analytical framework establishes a relationship between the effects and causes of a process. It is recognized that each effect has specific origins, allowing the inclusion of other causes that may arise during the development of the process (Rodrigues, 2006).

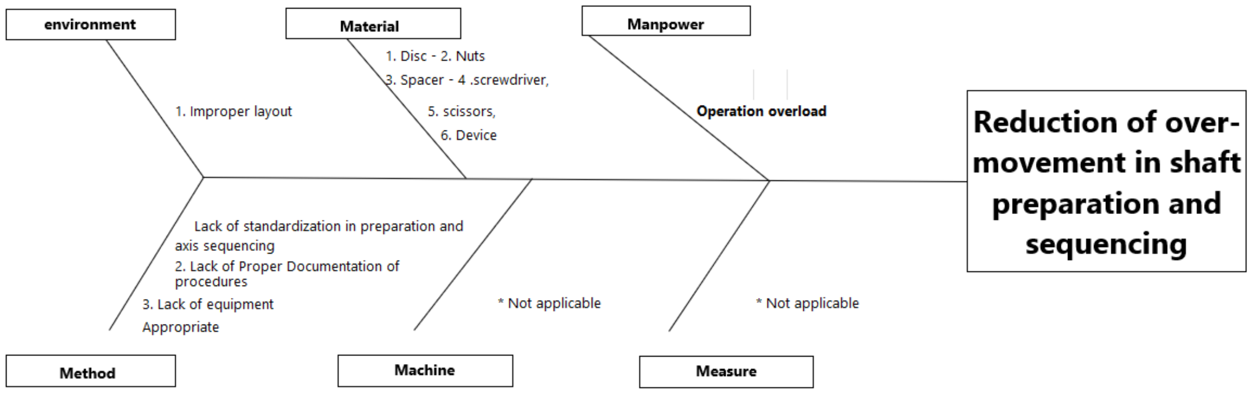


Figure 2. Ishikawa diagram reducing excess movement

The shaft must be unpacked, sequenced and with the discs assembled, before being sent to the assembly line.

Table 2. Potential Causes

| CAUSES | POTENTIAL CAUSES | | |
|---|---|---|---|
| | WHY 1 | WHY 2 | WHY 3 |
| **Reduction of excess movement in shaft preparation and sequencing.** | There is an excess of movement when preparing the shaft; | You need to transport several components to perform the same operation; | The shaft must be unpacked, sequenced and with the discs assembled, before being sent to the assembly line. |

According to Jucan (2005), the effort to identify the root cause of a problem is not an easy process, it depends on the experience of the team, in this context two main points are identified: first, the complexity of the operation due to the need for several procedures, tools and devices; second, the ample space required to move the axles with the Jeep, resulting in a significant operational displacement. Excessive complexity in performing tasks can lead to inefficiencies, while the extension of the environment contributes to wasted time and resources.

After a thorough analysis of the spaghetti chart and the Ishikawa Diagram by the Kaizen team, the initial objectives and goals outlined were shown to be guidelines for concrete actions. After brainstorming, the group intends to develop a multifunctional cart, capable of accommodating and transporting all the items, tools and devices essential for carrying out the operation, aiming at the optimization and practicality of the process. In addition, the team is committed to drastically reducing the number of steps involved in the current operation, aiming for a decrease of more than 30%.

This goal aims to simplify and improve workflow efficiency, providing greater agility and reducing potential errors. At the same time, another crucial objective is to considerably minimize the risk of accidents related to falling devices or injuries caused by overloading, aiming at a safer and more secure working environment for employees involved in the operational process. These goals reflect not only the pursuit of operational improvements, but also the commitment to safety and continuous improvement of procedures within the context of Kaizen.

An effort to find a solution was immediately initiated. Initially, a rudimentary sketch of a prototype was prepared to meet the identified operational demands. This prototype was conceived as an initial response to the emerging needs of the operation, serving as a basis for potential improvements in the process of preparing and sequencing the axes on the production line, as illustrated in Figure 3.

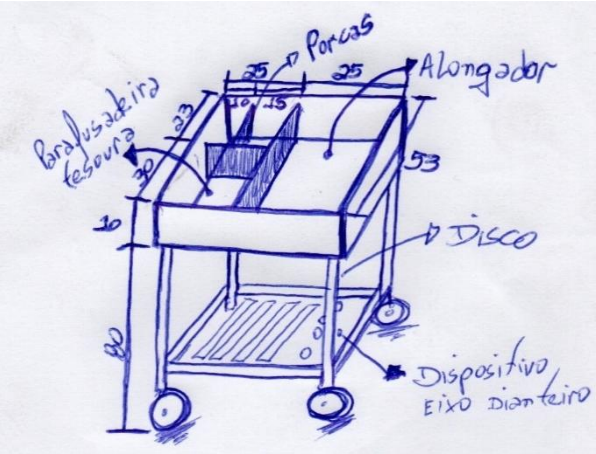


Figure 3. Sketch of the Cart Prototype

The dolly wheel is a versatile and adaptable solution, with a removable and recyclable structure. Its rugged tubular frame provides protection for parts and operators, resisting water, dust, corrosion, and solvents for durability in a variety of conditions. Made with 2mm aluminum tubes and reinforced joints, your 100mm Graphit wheel options ensure efficient mobility. Its divisions can be customized with nylon or PVC to meet specific needs, facilitating the efficient movement of loads and reducing the effort of operators, improving transport capacity and minimizing unnecessary movements – Does Not Add Value to Product (NAV).

Continuing the phases, the next step is the involvement of Logistics Engineering. Their team plays a central role in obtaining authorization to start production, carefully analyzing the logistical requirements for transportation, storage, and distribution of materials and components essential to manufacturing.

Release by the Cost Center involves analyzing the submitted budget, assessing whether the expected benefits outweigh the costs associated with the project. If the benefit/cost ratio is favorable, the start of production is authorized, ensuring that investments are in line with the expected returns for the organization.

In the Kaizen Workshop stage, logistics engineering is directed to an environment specialized in manufacturing and process improvement. Upon arrival at the workshop, the logistics team enters the order into the production queue, initiating the implementation process. This workshop, recognized for its focus on continuous improvements and efficiency in manufacturing, represents a strategic environment where demands are addressed and integrated into the production flow, aiming to improve logistics procedures and manufacturing practices.

In this Production and Delivery phase, the trolley is meticulously manufactured according to the specifications of the order, going through all the stages from production to assembly and finishing, using the necessary materials. Upon completion, the cart is delivered to the requester, meeting the established requirements and ready to meet the identified operational demands, as illustrated in figure 4.

Figure 4. Finished Dolly Wheel

In the Feasibility Testing stage, the candidate subjects the cart to tests to evaluate its effectiveness. The results reveal a significant reduction in the number of steps taken by the operator, decreasing from 899 to 219 after the cart was deployed. In addition, there was a notable increase in productivity: before, 36 vehicles were manufactured per operator/shift, while after the use of the trailer, this number rose to 41 vehicles, without the need for additional costs with hiring labor to meet demand, evidencing the positive impacts on efficiency and production flow.

In the feasibility testing process, considerable savings in physical and muscular strength were verified. This reduction contributed to reducing operator wear, avoiding physical overloads that could result in damage to health, in addition to providing a more ergonomically appropriate and safer work environment. These results reinforce the benefits of the trolley not only in terms of operational efficiency, but also in preserving the health and well-being of workers.

# 4 Conclusion

The study "Innovative Experiences in Engineering Education: Leveraging Continuous Improvement in the Automotive Industry" highlights the effectiveness of Problem-Based Learning (PBL) as the main methodology for the development of practical and analytical skills in engineering students. Through a case study in a heavy vehicle manufacturer, it was demonstrated that PBL, by enabling students to face real challenges and promote creative solutions, is fundamental for the training of engineers prepared for the market. The Kaizen methodology was used as a complementary support tool to PBL, facilitating the identification of opportunities for improvement and the development of effective solutions. This combination has resulted in significant improvements to the production line, including reducing the number of operational steps, increasing productivity, and improving the ergonomic conditions of workers.

If the Kaizen methodology had not been adopted as a complement to PBL, the learning outcomes would still have been significant, but with some limitations. The absence of Kaizen could reduce the emphasis on continuous and systematic collaboration, which is essential for developing communication and cooperation skills. Without the Kaizen philosophy, students might not experience the iterative practice of continuous improvement, which is crucial for efficiency and innovation in the automotive industry. In addition, students could develop solutions that are less applicable to the real world, limiting the relevance of their skills in the industrial context. Detailed analysis tools, such as the Ishikawa Diagram and spaghetti charts, could not be used, resulting in a less deep understanding of problems and their root causes.

Therefore, even without the Kaizen methodology, PBL would still provide robust and practical training, preparing students to face real challenges. However, the combination of PBL with Kaizen further enriches learning by encouraging a culture of continuous improvement and innovation. The experience documented in the study serves as an inspiring model for the integration of innovative practices in engineering education, demonstrating that the combination of PBL and Kaizen is highly beneficial for the training of qualified professionals who are adaptable to the constant challenges of the market.

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# Active Learning to Enhance the Architecture, Engineering, and Construction Sector

Shannon Chance[1, 2]

[1] School of Architecture, Building & Environment Research (SABER), Technological University Dublin, Dublin, Ireland
[2] Centre for Engineering Education (CEE), University College London, London, United Kingdom

Email: shannon.chance@tudublin.ie; s.chance@ucl.ac.uk

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**Abstract**

Active learning methods are integrated across the honors-level Bachelor of Science in Building Information Modelling (BIM/Digital Construction) at Technological University Dublin. Now in its fifth year of operation, the course provides mature students working (or aiming to work) in the Architecture, Engineering, and Construction (AEC) Sector across Ireland with a wide range of well-integrated and intellectually engaging hands-on learning opportunities. The Irish government financially supports this course because the Irish AEC sector needs state-of-the-art knowledge and skills to help modernize construction methods for this small island nation. The Irish government's support underscores the significance of the course in addressing the country's well-being. Hands-on aspects of the BIM curriculum include: researching to learn about digital principles and standards; modeling using Revit, ArchiCAD, MagiCAD, and the like; combining models from various engineering and design fields and then running clash detections and developing basic cost estimates, construction plans, and animations of project phasing/sequencing using Navisworks; applying principles at work via work-based learning in each student's workplace (or in an optional, simulated work environment); designing and conducting a research thesis project that involves reviewing published literature and case studies and sometimes documenting one's own case of integrating action-research methods; building web-based portfolios to showcase one's learning; authoring multiple reflective essays to develop one's skills in reflective practice; and applying agile team management strategies to organizing a team's work and managing a team's projects. We hope the design and reporting of this course will inspire others seeking to teach BIM, support mature students and working professionals, and/or integrate active learning methods in the classes and courses they teach.

**Keywords:** Active Learning; Pedagogy; Building Information Modeling; Architecture; Engineering; Construction.

## 1 Introduction

The Bachelor of Science in Building Information Modelling (BIM/Digital Construction) at Technological University Dublin (TU Dublin) offers a comprehensive curriculum to upskill engineers and professionals who enroll from across the Republic of Ireland. Through one year of intensive study, mature students acquire the necessary expertise to earn an honors-level Bachelor of Science degree. Major components of the twelve-month curriculum are work-based learning (15 credits in the European Credit Transfer System, ECTS, as per Table 1) and developing a concise research thesis/dissertation (15 ECTS, supported by a design phase of 5 ECTS). These two components work synergistically – empowering the hands-on application of theoretical knowledge via engagement in the workplace. The research, work-based, reflective, and team-based components enable students to apply BIM principles and standards – as well as project management and research methodologies – to address real-world challenges in the Architecture, Engineering, and Construction (AEC) sector.

Launched by TU Dublin in the spring of 2020, the course encompasses 60 ECTS overall. Modules meet in person one-half day per week and online two nights per week during two semesters. The cloud-based nature of BIM collaboration today provides an ideal environment for blended learning using (mostly) synchronous and (some) asynchronous approaches. Learning is mostly self-directed during the summer, where students apply new learning in the workplace for an eight-week period with periodic advice from an academic supervisor and a workplace mentor.

Table 1. BSc (Hons) BIM module sequence

| credits | module name | | | | contact |
|---|---|---|---|---|---|
| 5 | Digital Construction Principles & Standards | | | | 24 |
| 10 | BIM Architectural Modelling & Review | BIM Civil & Structural Modelling & Review | BIM MEP Modelling & Review | BIM Construction Model Exploitation & Review | 48 |
| 10 | BIM Federation & Validation | | | | 48 |
| 15 | Work-Based Learning | | Special Collaborative Project | | 16 |
| 5 | Research Methods | | | | 24 |
| 15 | Dissertation with Agile Project Management | | | | 30 |

The course's overarching goal is to equip graduates with the expertise to drive advancements in Building Information Modelling (BIM) and BIM Management (BIMM) practices throughout the Irish construction sector. Although we explicitly aim to generate new knowledge and provide an injection of new skills into the Irish AEC landscape, the methods we use hold relevance for anyone wanting to engage mature students in learning in a way that is academically rigorous and highly applied.

BIM and BIMM are essential tools in modern AEC, offering helpful solutions for digital project management. By fostering efficiency, reducing errors, and driving innovation across various project phases, BIM practices contribute to a more sustainable and productive construction industry. Consequently, the honors BSc course in BIM (Digital Construction) at TU Dublin helps inject new knowledge and skills into the Irish construction sector, enhancing the sector's overall effectiveness and competitiveness. The paper titled "Preliminary Mapping of Bachelors' Research to Enhance Digital Construction in Ireland" provides additional background on the course (Chance & McAuley, 2023a).

Consistent with the goals of Project Approaches in Engineering Education / Active Learning in Engineering (PAEE/ALE), the course design integrates many active learning (AL) methods. These are integrated into the course via group work, field- or work-based activities, project assignments, and a research thesis – all with reflective practice frameworks and project management approaches built in. The course leaders' earlier conference paper, "Infusing Research Know-How into the Construction Sector: Pedagogies to Support Digital Construction in Ireland," focused on student research (Chance & McAuley, 2023b). This paper moves the work another step forward, investigating how various AL pedagogies intersect to support student learning in BIM.

This PAEE/ALE conference paper and its presentation at PAEE/ALE 2023 are intended to help share knowledge and experience – and to support reflection and critique of the practices applied in this course. We hope that discussion during and after the presentation will help garner more diverse outsider perspectives to help us improve our course. We want it to generate new ideas for refining and extending our current approaches. The presentation will also provide audience members with new understandings of BIM, Digital Construction, and the integration of active learning across all modules of this course.

## 2 Literature Review

In higher education, "active learning" refers to instructional methods that actively engage students in the learning process, encouraging them to construct knowledge, solve problems, and apply concepts in meaningful ways. Active learning is recognized as an effective approach for promoting deeper understanding, critical thinking skills, and long-term retention of information among students (Prince, 2004). It is widely used in professional education, including the fields of pharmacy (Gleason et al., 2011), medicine (Barrows & Tamblyn, 1980), teacher education (Niemi, 2002), and engineering education (Prince, 2004).

Active learning pedagogies used in higher education include group discussions, debates, problem-solving activities, case studies, role-playing sessions, and the like (Heilporn et al., 2021). Teachers interviewed by Heilporn and colleagues explained that they "enhanced student engagement" by having students discuss "a topic or study a case in teams and then share their conclusions with the whole group. While team discussions enhanced student behavioral engagement through participation, different conclusions then generated whole group debates and promoted student cognitive engagement" (p. 10). Discussion in TU Dublin's BIM course works similarly.

Bean and Melzer (2021) discuss how writing relates to critical thinking and supports the development of such skills. They recommend providing rubrics to help direct students' efforts, "helping students use self-assessment and peer review to promote revision and reflection" (p. 231), and using portfolios to support knowledge-generation, record-keeping, and learning assessment. TU Dublin's BIM course uses reflective essays and e-portfolios for the purposes described by Bean and Melzer.

With a specific focus on blended learning environments and how to enhance students' engagement in courses that blend synchronous and asynchronous learning, Heilporn et al. (2021) assessed meta-cognitive aspects of learning. They looked at "(i) the course structure and pace; (ii) the selection of teaching and learning activities; and (iii) the teacher's role and course relationships" (p. 1). Except for the work-based learning component, our course is primarily synchronous, but it blends face-to-face and online learning.

In higher education, active learning is increasingly recognized as an essential approach for preparing students for the demands of modern professional fields, including the AEC sector. By actively engaging students in the learning process and encouraging them to construct knowledge, solve problems, and apply concepts in meaningful ways, active learning pedagogies foster more profound understanding, critical thinking skills, and long-term retention of information (Prince, 2004). This approach aligns with the dynamic and interdisciplinary nature of the AEC sector, where professionals must constantly adapt to evolving technologies, project requirements, and collaborative environments.

In the realm of engineering education, Hernández-de-Menéndez et al. (2019) described AL as "an interactive teaching method" (p. 910) and identified its primary attributes as:

- being a student-centered approach that puts the learner directly in the center of the process,
- letting students be the main protagonists of their learning process by performing meaningful activities and critically thinking about what they are doing,
- being a highly engaging method of education,
- encouraging the learner to participate actively by developing hands-on activities,
- focus students' engagement via learning objectives,
- increasing retention and understanding of knowledge because all the learning effort is exerted by the student themselves,
- having teachers assume the role of mentors and evaluators of the progress of the students, and
- taking advantage of a vast array of aids in order to capture and maintain attention of learners. (slightly adapted from the list on p. 910)

Research by Hernández-de-Menéndez et al. (2019) found that in engineering education, "this approach supports the development of in-demand competencies such as Teamwork, Problem-solving and Analysis. In addition, students' performance and retention rates are improved" (p. 909). The research team further noted that technology could be quite effective in helping support interactive teaching and learning in engineering.

Theoretical frameworks guiding the integration of active learning into BIM education at Technological University Dublin include Cottrell's (2023) model for facilitating critical thinking skills through analysis, reflection, and argumentation, as well as Bolton and Delderfield's (2018) guide to writing for reflective practice and professional development. Additionally, the Gibbs (1988) model provides a structured approach to guiding student reflection, which is crucial for promoting self-awareness and continuous improvement in professional practice. These frameworks serve as valuable tools for educators in designing and implementing active learning strategies that effectively prepare students for success in the modern AEC sector.

## 3 Active Learning Methods in BIM/Digital Construction Education

Active learning methods are integrated into every aspect of the TU Dublin BIM BSc course. Some ways we integrate AL are described in this section. We launch the course with an orientation/induction and then jump right in on the first day of the 12-month course with an 8-week-long set of two modules (depicted in Table 1). The first pair of modules covers foundational skills and knowledge.

### 3.1 Principles, standards, and modeling

The students all complete a 5 ECTS module on "Digital Principles and Standards" (or "DPS") together as a single cohort. For their 10 ECTS modeling modules, they break into streams (Architecture; Civil & Structural; Mechanical, Electrical, and Plumbing (MEP)) to learn to model buildings using software tools like Revit, ArchiCAD, and MagiCAD. The remaining stream, Construction Management, helps students learn to use and "exploit" models built by others, as professionals working on sites can benefit from doing. The DPS module also provides a basic introduction to academic writing and database searching; it includes research activities focusing on digital principles and standards currently underpinning BIM practice in Ireland and the UK. DPS also provides hands-on workshops in environmental sustainability and "LEAN" construction principles.

### 3.2 Multi-disciplinary federation and validation of models

The students bring their modeling knowledge forward in the subsequent "Federation and Validation" (F&V) module at 10 ETCS, where they work in teams of students from each stream who bring their models together, run clash detections, and resolve errors. Teachers and the students from the Construction Management stream guide each team in using Navisworks to integrate and analyze their models, and to use the software for cost estimating and construction staging/planning. The module currently uses BIM360 as a platform for collaboration.

Alongside this F&V module, students prepare for both their 8-week field-based Work-Based Learning (WBL) module (to be conducted over the summer break) and the research dissertation they will complete during the autumn semester. To prepare for the dissertation, they take a 5 ECTS module called "Research Methods" that guides them through identifying a research problem, a research question, and three research objectives aligned with methodologies for addressing the objectives and answering the research question. They need to explain the relevance of the research to their work setting and how it ties to the course.

### 3.3 Work-Based Learning

The "Work-Based Learning" (WBL) module allows students to apply digital methods for BIM in an approved workplace context. As the workplace context can differ significantly from student to student, the learning outcomes of the module focus on transferrable and generic skills, as well as the associated competencies identified in the frameworks of professional bodies such as Engineers Ireland, the Society of Chartered Surveyors Ireland / Royal Institution of Chartered Surveyors, and the Chartered Institute of Building (as appropriate to the individual student).

Each student also identifies a BIM-related task that requires stretching their abilities and applying new aspects of BIM, learned in the course, within their work environment. Students can: (a) undertake project that supports the completion of their Dissertation, (b) utilize Autodesk Revit, underpinned by ISO-19650 standards, to model a project previously undertaken in AutoCAD / 2D methods to demonstrate the benefits of BIM, (c) revisit a project that was undertaken without the utilization of ISO19650 or a proper BIM Execution Plan then reproduce discipline-specific project information and a range of models/model elements based on a standardized BIM Execution Plan under ISO 19650, (d) utilize Autodesk Revit to create new/bespoke families/elements modeled from existing drawings/point cloud data/existing data/supplier information OR utilize model elements/families in a new or existing project, with full ISO19650 standards implementation; (e) undertake a set of Autodesk Revit modeling tasks relevant to their role within an ISO19650 project being undertaken/planned by their organization; (f) critically document their organization's workflow and make recommendations on how a digital construction workflow can be implemented to advance data capture and communication channels; or (g) utilize Autodesk Navisworks underpinned by ISO-19650 standards, to coordinate a project that has recently used, or is currently using, 3D models to demonstrate the benefits of BIM. The project (or set of tasks) should take 15-20 days of 7.5 hours each (totalling115-150 hours).

The remainder of the 300 WBL hours are dedicated to planning the WBL experience, including a written critique of the student's current work role versus the potential of the student's role in an organization where BIM is fully implemented on all projects. They draw from the literature and relevant professional standards (e.g., ISO16950) and frameworks (e.g., WELL, LEED, BREEAM, BSRAI, CIBSE, SCSI, ASHREA, etc.) and apply these at work. They schedule, prepare a video for, attend, and report on a virtual Site Visit with their academic supervisor and work-plan mentor. They log several reflective journal entries and draft a Final Reflective Practice Report.

It is important to note that while the students are taking F&V, they also work on the work plan for their Dissertation and for WBL, both of which stress real-world applications and address current challenges faced by the students, their employers, and the larger sectors of BIM and AEC.

## 3.4 Research Methods and Dissertation

In the 5 ECTS "Research Methods" and 15 ECTS "Dissertation including Agile Project Management," the students learn to improve their project objectives and/or hypotheses iteratively, based on the identification of a program-related problem. They select, defend, and apply suitable academic methodologies to achieve their stated objectives. Each student conducts a critical review of current scholarly literature and relevant professional sources – reflecting upon standard theories and their inherent assumptions. The student formulates a solution for a semi-complex problem, considering ethical implications and assessing and managing risk. The students implement their proposed solution in industry-relevant settings, report and assess the outcomes of their proposed solutions (after investigating the underlying theories and examining the potential benefits of their solution to professional practice in terms of, for example, improved performance), using reliable appraisal methods. They identify deficiencies, risks, and fitness-for-purpose of their solutions; and iteratively produce a draft research paper to "starter" conference paper standard. Some of these BSc papers have gone on to presentation and publication at conferences (Martin et al., 2021; McLoughlin & McAuley, 2022; Grego et al., 2023). We are proud of the quality of the Dissertations produced and have been tracking and assessing the value of the work (see Chance & McAuley, 2023a, "Preliminary Mapping of Bachelors' Research to Enhance Digital Construction in Ireland").

The students also record the evidence for their learning journey, from problem identification to evaluation of the solution, in an appropriate structure using a personal e-portfolio and reflect upon their learning, particularly about integrating the knowledge gained in previous modules, using both continuous and summative entries to a personal, online e-portfolio (using Adobe Portfolio with One Drive file storage). Building the web-based portfolios is intended to showcase students' learning and help students direct some of their efforts to recognize what and how they learn and consider how to improve over time. In this, they author reflective essays to develop reflective practice skills.

During the Dissertation module, the students are guided to apply agile project management strategies, including SCRUMs (a form of management used for software development), that help teams respond quickly and effectively to quickly changing content and the incremental development, testing, and release of new software products.

Throughout the course, the students can access an extensive array of BIM, collaboration, project management, and presentation software platforms and tools. They get exposure to LinkedIn Learning (LIL) for self-directed exploration, and many of them upload certificates of completion for related LIL courses (e.g., Dynamo, project management, facilities management) even after graduation.

## 3.5 Learning Outcomes of the Course

Learners must demonstrate the required learning outcomes at this BSc course's end. They each create a discipline-specific BIM model utilizing industry-leading software and relevant standards. They utilize appropriate BIM standards and guidance materials within appropriate workflows. They effectively coordinate BIM models among disciplines and determine the effectiveness of processes and standards associated with BIM coordination. In this, they exploit BIM models for a range of tasks related to coordination, cost, energy, and design, and they validate the outcomes. They also define the requirements for low-energy building construction and interpret the outcomes of decisions around building materials and methods. They use and evaluate various digital and cloud-based technologies and tools to support multidisciplinary coordination and workflows.

Because we have four different streams, some learning outcomes vary. However, by the end of the course, most learners will also be able to create BIM objects and families, utilize BIM modeling software to achieve energy targets, and incorporate various information sources into BIM models (e.g., point clouds, existing building surveys, and facilities management information).

The curriculum is designed to align with TU Dublin's Graduate Attributes, which aim to foster enterprising skills such as innovation, leadership, collaboration, and entrepreneurship. Through workshops, engagement opportunities, and collaboration with TU Dublin's support services, professional bodies, organizations, and employers, the program aims to enhance students' job readiness. Professional development is integrated from the program's outset to support a variety of learners (specifically, those already in employment, those seeking role changes, and those currently unemployed or returning to work after a career break) with tailored re-entry workshops facilitated by industry experts.

Students are encouraged to develop target attributes, including becoming innovative leaders and effective collaborators in BIM. Teachers emphasize the importance of global responsibility, ethical conduct, motivation, and effective communication – within teams and across engineering fields. Inquiry-based approaches cultivate learners' critical thinking, problem-solving, knowledge creation, and decision-making skills. The program emphasizes disciplinary knowledge, reflective practice, work-based learning, and digital literacy, promoting continuous improvement and preparation for careers where ongoing learning is essential. Effective teamwork, emotional intelligence, strategic thinking, and resilience are also emphasized to prepare students for success in the collaborative environment of BIM coordination.

# 4 Assessment and Quality Assurance Procedures

Although a detailed description of quality assurance is beyond the scope of this report, it is worth noting that the course is rigorously assessed via formal procedures. These include continual data collection, course-refinement activities, and twice-annual assessments by external examiners who provide feedback and have helped hone the course over the years.

Assessment and quality assurance (QA) at TU Dublin is coordinated by the Program Chair, Head of Discipline, and the college's Head of Learning Development. The course was validated by Ireland's Higher Education Authority (HEA) in 2018 and is continuously reviewed today. We use structured rubrics to assess student performance; they help us provide formative and summative feedback in most modules and support reliable and replicable reviews by multiple staff members. Most grades are determined by two teachers, and we assess the evaluations for consistency – in any instance where the scores of two raters vary by 15% or more, we enlist a third reviewer.

All grades are uploaded by the respective module teachers and reviewed by a Module Board. This Board includes two external examiners – one from industry and one from another academic institution offering similar subjects – to help ensure validity, coverage, rigor, and fairness.

A Program Review committee (comprised of a student representative from each stream and all staff teaching the course) meets each semester to consider student feedback, address emerging concerns, and identify action items to enhance the course design and delivery.

We also conduct surveys and combine the results with the evaluations gathered from the Program Committee into formal reports. All agendas, minutes, and reports are provided to students and staff for review and to ensure open communication.

Statements from the most recent external examiners' report (2023) tie directly to topics highlighted in the literature review above, on active learning:

"The **Project-based approach**, both at individual and group level, is very practical and reflects industry situations." Moreover, "**Practical project-based approach** to teaching BIM/Digital Construction using multi-disciple **teams** reflects Industry situation."

"Programme content is extensive and all modules are relevant to Industry needs [both present and future]. While the volume of content and assignments seems intensive, it allows students to sample potential areas of BIM/Digital Construction through further studies or within Industry."

"Most students benefitted from the **Reflective Learning process**."

"Marking schemes for modules correctly reflect the practical focus of Module learning outcomes" and "Marking of assignments was very fair and consistent across all students and modules. Students were given every opportunity and support to achieve their best result through constant feedback and marking rubrics in particular." Additionally, "The level of **engagement, support and feedback from staff**, in particular the **marking rubrics** and the sense of an open-door approach, provides students the greatest opportunities to develop their skills and reach their potential."

The 2022 report from a different examiner stated, "The program was consistently and fairly marked. The **marking rubric** layout clearly where marks were gained and lost and provide good feedback to students."

The 2022 report from a third examiner explain that the "Comprehensive **grading rubrics** [provide] clarity for students and supports consistency where multiple examiners are involved." The evaluator noted improvement in the course design over time: "The one aspect for improvement that I raised following my first visit was to reconsider evidence provided to demonstrate that students had achieved the learning outcomes in relation to the '*WKPL 1004 – **Work Based Learning***' module. As a 15 ECTS module [...] its significance in contributing to overall programme outcomes should not be underestimated. To the credit of the programme team, they have responded and the module is developing positively and builds on the success of the first year. Again, the inclusion of this module is to be commended as the inclusion of significant work placement elements is beginning to realise increased prevalence in third level education and the development of such modules can prove challenging."

# 5 Reflection and Critique of Current Practices

A snapshot of our ongoing and structured approach to evaluating the effectiveness of our active learning pedagogies for helping achieve course objectives is provided above. The strengths of the current course structure are reflected in the quality of the models and collaborations as well as the WBL and research outputs generated to date. Weaknesses in the current course structure are the very high level of engagement students must sustain for 12 continuous months; that said, the degree they earn (an honors-level bachelor's degree founded on Recognition of Prior Learning) is prestigious and very well recognized across the Irish AEC sector.

Through Ireland's well-established QA process, the staff, led by the Program Chair (Shannon Chance) and the Head of Discipline (Barry McAuley), have continually identified and addressed areas for improvement – many of these related to streamlining the submission requirements to avoid unnecessary duplication of work and harmonizing the schedule. We periodically run pilot tests of scheduling refinements to achieve just-in-time delivery of content that the students can immediately apply.

As one cohort of students seemed unaware of the time-consuming nature of the course, in December 2022, we started conducting a pre-orientation to help students visualize what lay ahead so they could plan accordingly. The student has indicated that this helped them prepare and acclimate. The 2023 external examiner's report explained, "Students were thankful for the Pre-induction process as it highlighted the level of commitment required for the course and motivated them to set-up support systems to help e.g., with family or work."

Despite the (pre-induction and induction) emphasis on allocating enough time, some students still drop the course in the first month. We find this unfortunate, but also acknowledge that our drop-out rate is in line with these types of training courses for job-seekers. The required commitment is high as this is the equivalent of a full year of full-time study (60 ECTS). Most of our students complete it on top of full-time employment and the family responsibilities that mature students often balance.

Just a week before the writing of this paper, we found ways to streamline our WBL experience a bit more, for example. We removed the reflective journal entry used to report the outcomes of the site visit and tucked this expectation into the Final Reflective Practice Report (where students are provided an outline of points to address). We removed the requirement to make a formal WBL presentation at the end of the summer, as this requirement seemed to present a mental block for students to embrace the work fully necessary for their Dissertations until after the presentation date. The short video that we now request they produce for the virtual Site Visit is used in lieu, but the Final Reflective Practice Report still requires them to make the critical appraisals that were previously presented to 4-5 other peers.

# 6 Future Directions and Implications

In the coming years, we will need to assess how the changes to the WBL module play out – to ensure that we are still meeting the full range of Learning Objectives specified in our Module Descriptor.

We recently applied for a few modifications to the set of Module Descriptors validated initially in 2018. We more explicitly called out the integration of sustainability, ethics, and diversity issues into various modules.

Our biggest challenge has been introducing mature students to academic writing, as this is not part of their day-to-day job, and most have not done this at the university level before. We have found that they are well up to the challenge, given a structured approach with limited options (there is no time in this condensed format for them to collect survey or interview data, so their research relies on literature review, case study, and/or action research methods). We have had good results by encouraging students to integrate their WBL and Dissertation work as much as possible, so that they conduct a lot of their research design and literature review prior to commencing WBL, so that they can apply techniques and collect data in situ – that they can subsequently write up for the Dissertation module.

We have tested various timings for the delivery of the Research Methods module, and currently provide most of that structure learning during the spring semester, with the final research Proposal Form (research work plan) presented and written up for submission at the end of the summer.

One challenge has been to hit the optimal level of work for the Dissertation. Based on our prior research (Chance & McAuley, 2023a, 2023b), we recognized that there might not be enough distinction in quality between our MSc and BSc dissertation outputs. We made more explicit the option for students to use literature reviews and published case studies (i.e., secondary research) to answer all objectives. We also pilot-tested a drop from 6000 words (±10%) to 5000 words. In the coming iteration, we will allow anything in the range of 5000-6000±.

As active learning pedagogies are embedded in every aspect of these modules, we do not see the need to add new AL components. We will, however, look for additional ways to streamline so that we get the most authentic learning – and the greatest positive effect from the students' engagement.

Yet, we note the great potential for broader application of active learning methods in similar educational programs in Ireland and beyond. Moreover, considering the implications of this present study for BIM education and the AEC sector in Ireland, and in light of findings from Chance and McAuley (2023a, 2023b), we now propose to conduct a new study to evaluate the effectiveness of the BIM/Digital Construction courses at TU Dublin in nurturing leaders who have made significant contributions to the Irish AEC sector. By engaging graduates from our various BIM courses, we intend to assess the career trajectories and leadership roles these individuals have assumed following their BIM education. For this, we propose to adopt a leadership model, e.g., Fullan (2007) or Black and Gregerson (2013) – and then develop a survey instrument around the model and conduct it with all graduates of our BSc and MSc BIM courses.

# 7 Conclusion

A prior review of bachelor's research topics by Chance and McAuley (2023a) provided insights into the focus areas for BIM students. A common thread across the BSc dissertations was an emphasis on national-level issues, with many students exploring the possibilities of new processes or tools, especially in architecture and construction. Topics including LEAN practices, heritage conservation, and modular prefabrication were common. Of the 59 BSc dissertation studies completed by that date, three had achieved significant recognition, contributing to areas like energy-efficient design (Grego, et al., 2023), structural design optimization (McLoughlin & McAuley, 2022), and enhancement of estate management within the healthcare sector (Martin et al., 2021).

The Chance and McAuley (2023a) paper stressed the importance of research skills in shaping students into effective practitioners. With students now assuming leadership roles and driving changes within the Irish construction sector, the next step is to understand the real impact of TU Dublin's BIM courses. The research team will soon shift focus toward surveying past students – in order to assess how well the BIM courses have equipped individuals to contribute as leaders in the Irish AEC sector.

In conclusion, this paper has provided a chance to reflect upon the importance of active learning in BIM education and its impact on student learning and professional development. Ongoing reflection is necessary – not just as a skill for our students to learn – but as a crucial activity for helping us improve the design and delivery of this course, which holds great relevance and promises to enhance AEC practices across Ireland.

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# Active Learning for Introduction to Engineering Courses: the University of Brasilia Production Engineering Case as Support for a Unifying Proposal Centred on PBL & Flipped Classroom

João Mello da Silva[1], Paulo Celso dos Reis Gomes[2], Simone Borges Simão Monteiro[3], Marcelo Carneiro Gonçalves[4], Clóvis Neumann [5], Adriano Possebon Rosa[6], Henrique Cezar Ferreira[7], Mateus Halbe Torres[8]

[1] Graduate Program in Applied Computing, University of Brasilia
[2] Faculty of Technology, University of Brasilia
[3,4,5] Department of Production Engineering, University of Brasilia
[6] Department of Mechanical Engineering, University of Brasilia
[7] Department of Electrical Engineering, University of Brasilia
[8] Department of Electronic Systems, Aalborg University

Email: joao.mellos@gmail.com, pcrgomes@unb.br, simoneborges@unb.br, marcelo.goncalves@unb.br, clovisneumann@unb.br, possebon.adriano@gmail.com, henrique@ene.unb.br, mhto@es.aau.dk

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**Abstract**

This paper describes the application of active learning methodologies in the Introduction to Production Engineering (IEPR) course at the University of Brasília since 2018, highlighting the use of Problem/Project-Based Learning (PBL) and Flipped Classroom. IEPR, centered on workshops, emphasizes real-life problems and opportunities, including projects related to sustainable, innovative, privacy-protecting, and business-oriented systems. This approach has allowed the IEPR to be categorized as an extension activity. Four anchors support the IEPR workshops: Reality (A1), involving megathemes and corresponding stakeholders with real problems and opportunities, as well as scientific publications; Methodology (A2), which considers regulated professional sectors, academic evaluation, and areas of interest for professional associations, developing teamwork through PBL and Flipped Classroom to understand engineering with a focus on Production Engineering, prepare educational materials (graphics, texts, posters, videos), deliver lectures, formulate questions to assess learning, interact with stakeholders and competent entities, perform bibliometric searches, consolidate teamwork in video format, and report lessons learned; Specific Contents (A3), covering topics from the Production Engineering Program at UnB, Introduction to Systems Approach, Learning and Teaching Organization as a Purposeful System, Legislation and Regulations: Professional Attributions, Academic, Professional Association Interests, Technical and Scientific Writing; and Other Anchors (A4), including other issues, essentially other courses, with interest in IEPR topics. The proposal is to use the IEPR framework as a template to create preliminary versions of other Introduction to Engineering courses with the same structure. From a broader perspective, the IEPR framework may serve as the basis for establishing an Introduction to Engineering Course (IENG) encompassing Production Engineering and other undergraduate engineering programs at the Faculty of Technology at UnB.

**Keywords**: Active Learning, Problem-Based Learning (PBL), Flipped Classroom, Introduction to Engineering, Production Engineering

## 1 Introduction

This paper addresses the application of active learning methodologies, specifically Problem-Based Learning (PBL) and Flipped Classroom, in the Introduction to Production Engineering (IEPR) course of the Undergraduate Program in Production Engineering at the Faculty of Technology of the University of Brasília (PEUP-UnB) since 2018. Additionally, it presents a proposal for adapting the framework used in IEPR to other Introduction to Engineering courses under the umbrella of active learning approaches.

In addition to PBL, IEPR includes the Flipped Classroom as an active learning tool to build the Content Integration Workshop (CIW-IEPR), which constitutes the fundamental working environment for teamwork. Four anchors (A1 to A4) support the CIW-IEPR: A1-REALITY: real-life megathemes for teamwork (focused on sustainability, innovation, privacy, and decision-making adjusted to risk), including interaction with stakeholders and/or people and entities with competencies on the megatheme; A2-METHODOLOGY: student project groups (three to five participants) develop teamwork using PBL and Flipped Classroom active learning tools, focusing on Anchor A1 megathemes; A3-SPECIFIC CONTENTS related to the megathemes to support teamwork sessions; and A4-OTHER ANCHORS: especially other courses with interest in IEPR project topics.

The remainder of the paper is divided into three chapters. Chapter 2 outlines IEPR in terms of the specific contents for teamwork in Content Integration Workshops (CIW-IEPR) focusing on Megatheme1: Understanding Production Engineering in Brazil, including individual questionnaires on it; and Megatheme2: Applications of Production Engineering on components of solid waste systems, including bibliometric searches and/or interactions with stakeholders, persons, and entities with competencies on the subject.

Chapter 3 details the four anchors of the Content Integration Workshop (CIW-IEPR): A1-Reality: Megatheme1 and Megatheme2, including orientation on technical and scientific writing; A2-Methodology: PBL and Flipped Classroom; A3-Specific contents: all those outlined in Chapter 2; and A4-Other anchors: emphasis on other courses, both inside and outside the Faculty of Technology, with interest in IEPR project topics.

Chapter 4 summarizes the material presented in Chapters 2 and 3, proposing an Introduction to Engineering course that merges IEPR and other Introduction to Engineering courses at FT/UnB, under the supervision of both the Faculty of Technology Direction (FTD) and the Faculty of Technology Extension Coordination (EC/FT), with the details of each Engineering Undergraduate Program continuing under the responsibility of the corresponding Academic Coordination. This includes: 1-The adoption of active learning approaches to other Introduction to Engineering courses, emphasizing PBL and Flipped Classroom as a requirement; 2-An initial week Opening Ceremony, including: a-FTD Welcome to freshmen of the Faculty of Technology Engineering Undergraduate Programs (EUP/FT); b-Presentation of the EUP/FT by both EC/FT (presenting the extension activities involved) and the corresponding Academic Coordinator of each Engineering Undergraduate Program (detailing the program under his/her responsibility); 3-A last week Closing Ceremony: a-Summary of the teamwork results, presented by both FTD and EC/FT; b-Presentation of the best teamwork results in terms of consolidated videos; c-Possible comments on the project results achieved by stakeholders and/or persons and entities with competence on the subjects; d-Recognition of the best teamwork results, with certificates issued by FTD and/or EC/FT.

## 2 The Introduction to Production Engineering (IEPR) course at FT/UnB

The Introduction to Production Engineering (IEPR) course, a PEUP-UnB required first-semester course, is designed not only to understand Production Engineering as a profession in Brazil but also to explore sustainable, innovative, privacy-protecting applications with decision-making adjusted to risk. To achieve this, IEPR adapts the Project-Based Learning (PBL) approach used in the Production Systems Projects courses (PSP1 to PSP8), which begin in the fourth semester of PEUP-UnB.

IEPR extensively uses two active learning approaches: 1) PBL (Christie & de Graaff, 2017; Edström & Kolmos, 2014; de Graaff & Kolmos, 2007; de Graaff & Kolmos, 2003; Kolmos, 2009; Lima et al., 2017; Lima et al., 2007) and 2) Flipped Classroom (Derek BOK Center, 2024).

After summarizing the competencies of an engineer in terms of knowledge ("intelligence"), skills, and attitudes, the course includes a description of the PEUP-UnB components (Lima et al., 2012; Silva et al., 2013; Silva et al., 2016; Silva et al., 2017): Mathematics, Physics, Information Systems, Technology, Production Engineering Basics, Advanced Production Engineering contents, related elective contents, great themes, synthesis, integration and entrepreneurship, supervised internship, graduation projects 1 and 2, complementary activities, and free choice of elective contents.

Next, the course introduces systems approach (Ackoff, 1974; Ackoff & Gharajedaghi, 2011; Bunge, 1989; Checkland, 1981; Ögden & Richards, 1923; Jaguaribe, 1973; PMBOK 6, 2017; Tolk, 2010; Turnitsa et al., 2010; Wang et al., 2013; Hamasaki et al., 2022), covering the semiotic trapezoid, categorization according to cardinal points, modeling attributes, open system description, open systems in regard to the purpose of the whole and its parts, and society models.

The course considers learning and teaching organization as purposeful social system (Garavan, 1997; Pedlar et al., 1991; Lourenço et al., 2023; Romme & Arjen, 1999), oriented to sustainability, innovation, privacy protection, and decisions adjusted to risk (United Nations 2030 Agenda, 2015; OECD/Eurostat, 2018; Brazilian General Data Protection Law – LGPD, 2020; GDPR, 2016; Fair Information Practice Principles – FIPPs, 2016; FIPPs at Berkeley, 2024). It is emphasized the excellence in multiple learning and teaching levels (Wasdell, 1993: efficiency, efficacy, eminence, effectiveness), the increasing degrees of organizational evolution (existence, experience, emergence, evidence), and considered the competing values framework ("complementary organizational values") (Cameron, 2024; Robert E. Quinn's Competing Values Framework, 2024; Tianyuan Yu et al., 2009).

The course summarizes legislation and regulations regarding professional attributions (Brazilian Engineering and Agronomy Federal Council – CONFEA: CONFEA, 2005a; CONFEA, 2005b; CONFEA, 2013; CONFEA, 2016) and academic matters (Ministry of Education – MEC: MEC, 2019; MEC, 2023a; MEC, 2023b; MEC, 2023c), complemented by the areas of interest of both, the Brazilian Production Engineering Association (ABEPRO) and the Institute of Industrial and Systems Engineers (IISE).

Given that most teamwork activities result in written materials required to be presented in both Portuguese and English, it is mandatory to introduce the basic concepts of technical and scientific writing in both languages (Machado, 2024; Gonçalves et al., 2023; Perelman et al., 2024). To consolidate part of the conceptual material, students must answer questionnaires on sustainability, innovation, and privacy protection before starting teamwork activities. Figure 1 synthesizes the IEPR description.

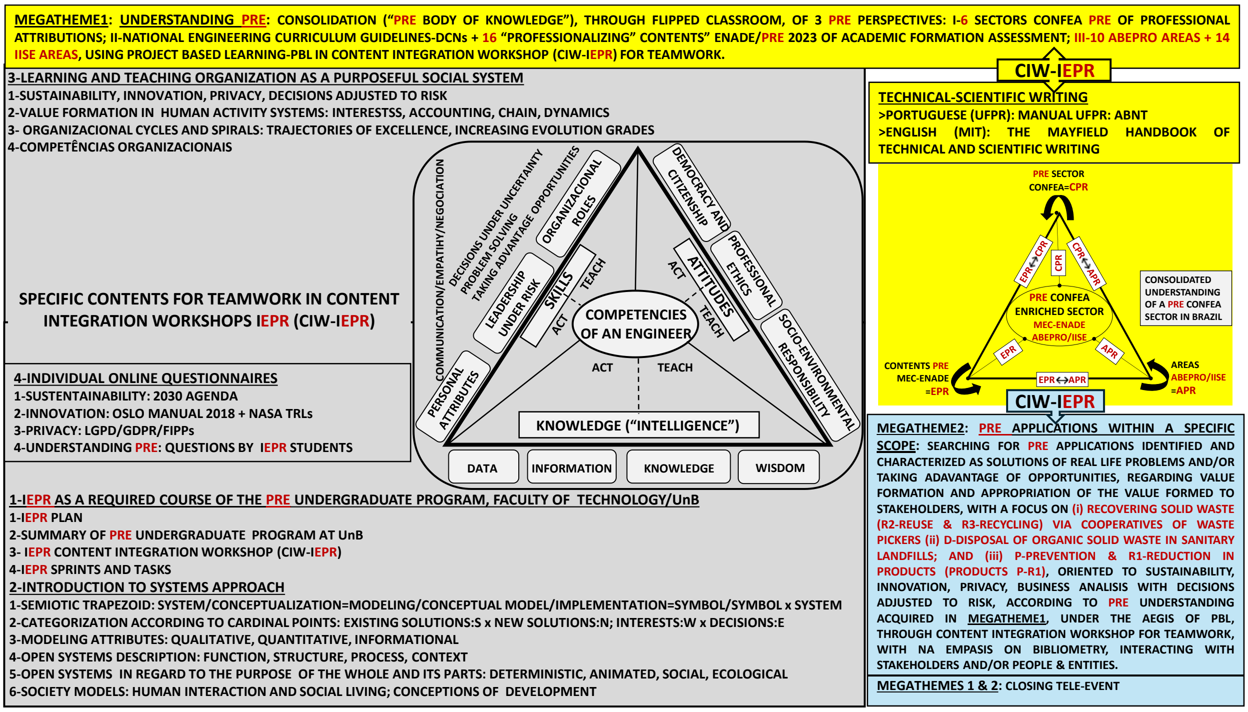


Figure 1. Synthesis of IEPR Description

# 3 The IEPR Content Integration Workshop (CIW-IEPR)

PBL and Flipped Classroom are the active learning tool used to build the IEPR Content Integration Workshop (CIW-IEPR), fundamental working environment for teamwork. As shown in Figure 2 (adaptation of Figure 7.4 of Guerra et al., 2017), four Anchors (A1 to A4) supports CIW-IEPR:

**A1-**REALITY: megathemes and their stakeholders and/or people and/or entities with competence in them:

- Megatheme1: Understanding Production Engineering in Brazil under three perspectives: 1) six regulated professional sectors; 2) sixteen academic evaluation contents; and 3) ten ABEPRO and fourteen IISE professional association interest areas.
- Megatheme2: Considering the PRE understanding acquired through Megatheme1, identify and characterize PRE applications in components of Solid Waste Systems, categorized according to PRE CONFEA sectors.

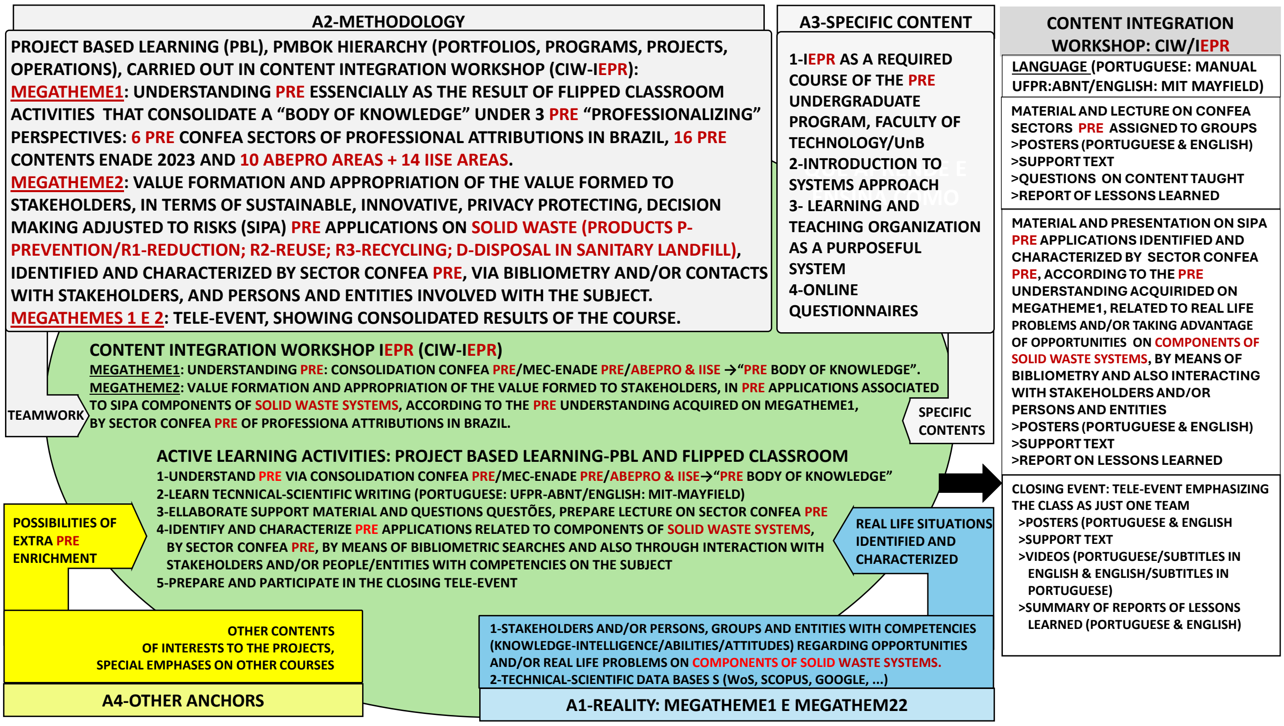


Figure 2. Content Integration Workshop (CIW-IEPR) for IEPR Teamworking

**A2-**METHODOLOGY: Student project groups (minimum of 3 and maximum of 5 participants) develop teamwork using Flipped Classroom and PBL related to Megatheme1 and Megatheme2 of Anchor A1:

- **Megatheme1**: Considering the 1) six regulated professional sectors; 2) sixteen academic evaluation contents; and 3) ten ABEPRO and fourteen IISE interest areas of professional associations, the teamwork (i) understand engineering, with an emphasis on Production Engineering; (ii) prepare educational material (graphics, texts, posters, videos); (iii) present a lecture on one of the six PRE CONFEA regulated professional sectors; (iv) formulate questions for a questionnaire to assess the learning of the session content; (v) interact with stakeholders and/or competent people and entities related to Megatheme1; (vi) performs bibliometric searches on Megatheme1 subjects; and (vii) reports lessons learned. Table 1 shows the components of the three Production Engineering perspectives: Professional Attributions, Academic Formation and Assessment, and Areas of Interest of Professional Associations.

Table 1. Components of Three Production Engineering Perspectives in Brazil

| PERSPECTIVES FOR UNDERSTANDING PRODUCTION ENGINEERING IN BRAZIL | | | |
|---|---|---|---|
| PROFESSIONAL ATTRIBUTIONS CONFEA/CREAS 6 SECTORS | ACADEMIC FORMATION&ASSESSMENT MEC/CNE/CES/INEP/ENADE 2023 16 "PROFESSIONALIZING" CONTENTS | AREAS OF INTEREST OF PROFESSIONAL ASSOCIATIONS | |
| | | BRAZILIAN PRODUCTION ENGINEERING ASSOCIATION (ABEPRO): 10 AREAS | INSTITUTE OF INDUSTRIAL AND SYSTEMS ENGINEERS (IISE): 14 AREAS |
| 1.3.21-ENGINEERING OF PHYSICAL PRODUCTION PROCESSES | EPR04-ENGINEERING ECONOMY | AB01-OPERATION ENGINEERING AND PRODUCTION PROCESSES | 1-WORK DESIGN&MEASUREMENT |
| 1.3.22-QUALITY ENGINEERING | EPR05-PRODUCT ENGINEERING | AB02-SUPPLY CHAIN | 2-OPERATIONS RESEARCH&ANALYSIS |
| 1.3.23-ERGONOMICS | EPR06-WORK ENGINEERING | AB03-OPERATIONS RESEARCH | 3-ENGINEERING ECONOMIC ANALYSIS |
| 1.3.24-OPERATIONS RESEARCH | EPR07-ERGONOMICS | AB04-QUALITY ENGINEERING | 4-FACILITIES ENGINEERING&ENERGY MANAGEMENT |
| 1.3.25-ORGANIZATIONAL ENGINEERING | EPR08-STATISTICS | AB05-PRODUCT ENGINEERING | 5- QUALITY&RELIABILITY ENGINEERING |
| 1.3.26-ENGINEERING ECONOMY | EPR09-STRATEGY AND ORGANIZATION | AB06-ORGANIZATIONAL ENGINEERING | 6-ERGONOMICS&HUMAN FACTORS |
| | EPR10-GRAPHICAL EXPRESSION | AB07-ENGINEERING ECONOMY | 7-OPERATIONS ENGINEERING&MANAGEMENT |
| | EPR13-ENVIRONMENTAL MANAGEMENT | AB08-WORK ENGINEERING | 8-SUPPLY CHAIN MANAGEMENT |
| | EPR14-PRODUCTION MANAGEMENT | AB09-SUSTAINABILITY ENGINEERING | 9-ENGINEERING MANAGEMENT |
| | EPR15-HYGIENE AND SAFETY AT WORK | AB10-EDUCATION IN PRODUCTION ENGINEERING | 10-SAFETY |
| | EPR16-LOGISTICS | | 11-INFORMATION ENGINEERING |
| | EPR19-OPERATIONS RESEARCH | | 12-DESIGN&MANUFACTURING ENGINEERING |
| | EPR20-MANUFACTURING PROCESSES | | 13-PRODUCT DESIGN&DEVELOPMENT |
| | EPR21-QUALITY | | 14-SYSTEM DESIGN&ENGINEERING |
| | EPR23-SYSTEMS SIMULATION | | |
| | EPR24-INFORMATION SYSTEMS | | |

- **Megatheme2**: Figure 3 shows a consolidated view of the Basic Sanitation System in terms of **1)** Portfolios (Water=W1, Sewage=S, Drainage and Rainwater=D, Waste=W2); **2)** Programs (Waste=W2: Prevention=P, Reduction=R1, Reuse=R2, Recycling=R3, Disposal in Sanitary Landfills=D); and **3)** Projects/Applications (Solid Waste Recovery via Cooperatives of Waste Pickers: R2-Reuse and R3-Recycling; Waste Disposal in Sanitary Landfills; and Product Engineering, with a focus on Prevention=P and Reduction=R1).
  Focusing on the components of Solid Waste Systems highlighted by dotted red lines in Figure 3, and taking into account the understanding of Production Engineering acquired through Megatheme1, the student groups: (i) perform bibliometric searches on Production Engineering applications (related to one of the six PRE CONFEA sectors) that are sustainable, innovative, privacy-protecting, with decisions adjusted to risk; (ii) interact with stakeholders and/or competent people and entities; (iii) prepare graphics, texts, posters and videos related to the components of Solid Waste Systems; (iv) present the results of teamwork to the class.

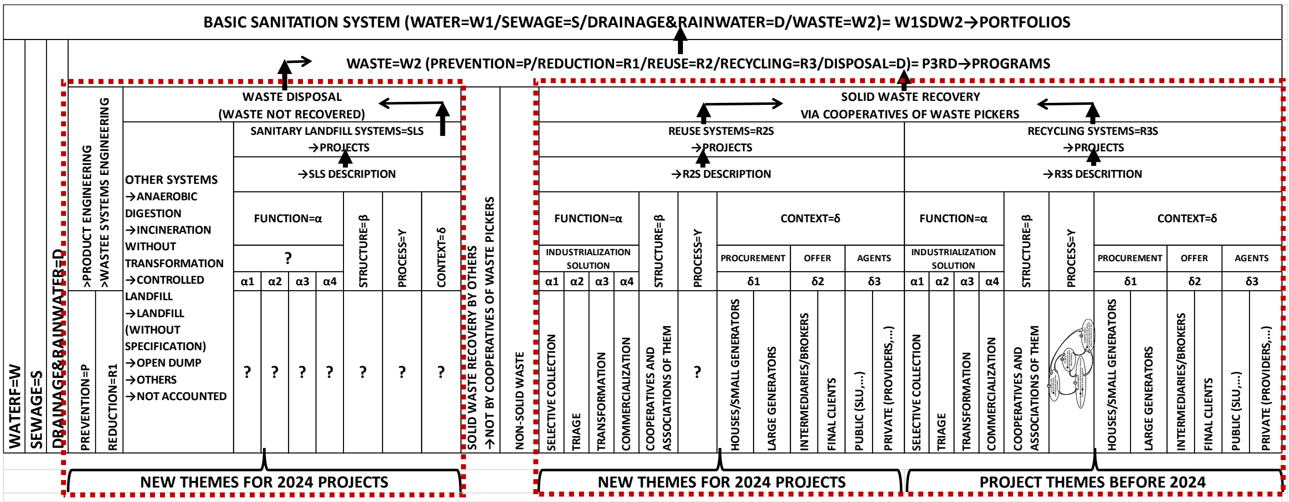


Figure 3. Basic Sanitation System: Focus on Solid Waste

**A3-**SPECIFIC CONTENTS: to be used during teamwork sessions, as detailed in Figure 2.

**A4-**OTHER ANCHORS: Enrichment by other contents, especially those brought by other courses.

The integration of these megathemes by the class as a team is essential for the preparation and participation in the IEPR closing event, demonstrating the collective understanding and application of the course concepts. The focus on both megathemes allows students to synthesize their knowledge of Production Engineering in Brazil and apply it to real-world scenarios, including sustainable, innovative, and privacy-protecting applications with decisions adjusted to risk. The approximate results achieved by IEPR during the 12-semester period since 2018 are the following:

- Students: 600,
- Student groups: 150,
- Group reports: 300,
- Closing tele-events: 12,
- 900 questions formulated by IEPR students related to the understanding of PRE in Brazil,
- Tutors and Monitors: 60, responsible for 1-Bibliometry tutorial, 2-Teamwork guidance, and 3-Preliminary assessment of group reports.

# 4 Proposal for Merging Introduction to Engineering Courses at FT/UnB

Figures 1, 2, and 3 can serve as templates for creating preliminary versions of other Introduction to Engineering courses with the same framework by substituting the words written in RED for the corresponding words of other Engineering Programs. For instance, replacing "PRODUCTION ENGINEERING" (PRE) by "MECHATRONICS ENGINEERING "(MTE)," and all text related to the focus of Megatheme2 by a subject of interest defined by the Mechatronics Engineering Academic Coordination. It follows a proposed general extended syllabus for an Introduction to Engineering Course (**IENG**) encompassing Production Engineering and other Undergraduate Engineering Programs at FT/UnB.

**Welcome Ceremony**: The welcome ceremony will include a general scope of Engineering with a particular emphasis on those Engineering fields with undergraduate programs at the Faculty of Technology (FT) of the University of Brasília (UnB). This segment will be presented by the FT Direction (FTD). Extension activities involved in IENG will be presented by the Extension Coordination of the Faculty of Technology of UnB (EC-FT/UnB). Additionally, there will be a summary of the Engineering Undergraduate Programs included in IENG, presented by the corresponding Academic Coordination.

**Contents (Responsibility of the Corresponding Academic Coordination)**: This section includes an introduction to the systems approach and learning and teaching organization as a purposeful social system, oriented towards sustainability, innovation, privacy protection, and decisions adjusted to risk. It also covers excellence in multiple learning and teaching levels (EX1: Efficiency, EX2: Efficacy, EX3: Eminence, EX4: Effectiveness), increasing degrees of organizational evolution (EV1: Existence, EV2: Experience, EV3: Emergence, EV4: Evidence), and considering complementary organizational values (C1: Create, C2: Collaborate, C3: Control, C4: Compete). There will be a summary of the legislation and regulations regarding professional attributions (Brazilian Engineering and Agronomy Federal Council – CONFEA and Brazilian Engineering and Agronomy Regional Councils – CREAs) and academic matters (Ministry of Education – MEC/National Education Council – CNE/Superior Education Chamber – CES/National Pedagogical Studies Institute – INEP/National Student Performance Exam – ENADE), complemented by a brief explanation of the areas of interest of a Brazilian Professional Association representing the Engineering field (e.g., the Brazilian Production Engineering Association – ABEPRO). Technical and scientific writing will also be covered in both Portuguese (ABNT Norms, as in UFPR) and English (Mayfield Handbook of Technical Scientific Writing, as in MIT).

**Teamwork**: Teamwork will involve the preparation and presentation of a lecture focusing on one of the CONFEA Technical Sectors of the corresponding Engineering field, including the formulation of questions to assess the understanding of the lecture content. It will also involve carrying out bibliometric searches on the understanding of the corresponding Engineering field, as well as sustainable, innovative, privacy-protecting applications with decisions adjusted to risk, associated with the subject of interest defined by the Academic

Coordination for Megatheme 2. Preparation and participation in the closing tele-event will aim to show the organization of the whole class as one team.

**Closing Ceremony**: The closing ceremony will include a summary of the IENG teamwork results, presented by FTD. Extension activities developed in IENG will be presented by EC-FT/UnB. The best teamwork results for each of the participating Engineering Programs will be presented in terms of consolidated videos. There will also be comments from stakeholders and/or other persons, groups, and entities interested in IENG, and recognition of the best teamwork results, with certificates issued by FTD and/or EC-FT/UnB.

# 5 Conclusion

Since 2018, this model has been implemented in the Production Engineering course at the University of Brasília (UnB), and it has already shown positive results with graduated students. The primary objective of this paper was to present a proposal for a model that can be adapted to other Introduction to Engineering courses using the same framework. Figures 1, 2, and 3 serve as templates for creating preliminary versions of these courses. From a broader perspective, the IEPR framework may serve as the foundation for establishing an Introduction to Engineering Course (IENG) that encompasses Production Engineering and potentially all other Undergraduate Engineering Programs at FT/UnB. This would be done under the coordination of the Faculty of Technology Direction (FTD) and the Extension Coordination of the Faculty of Technology (EC-FT/UnB), ensuring a cohesive and comprehensive approach to engineering education at the university. Although the model has shown promising results in the Production Engineering course, further research is needed to evaluate its effectiveness across different engineering disciplines. Future studies should focus on the adaptation process, evaluating the outcomes, and identifying best practices for broader implementation.

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# Academic Hackathon and PBL as an Awakening of Competencies for Social Entrepreneurship in Engineering Students

Afsaneh Hamedi d'Escoffier[1], Frederico Pifano de Rezende[2, 3]

[1] Lab. Protozoologia, Instituto Oswaldo Cruz, Fundação Oswaldo Cruz, Rio de Janeiro, Brazil
[2] Texas A&M University
[3] Instituto Federal do Espírito Santo, Espírito Santo, Brazil

Email: afsanehamedi@gmail.com, fredpifano@gmail.com

DOI: https://doi.org/10.5281/zenodo.14060742

**Abstract**

All over the world, there are social problems and needs that governmental, non-governmental, and market structures cannot recognize or respond to efficiently. In this context, social entrepreneurs fill this gap by finding innovative solutions and applying them with viable business models, considering social value and economic growth, and taking an above-average risk in creating and disseminating social value. Social entrepreneurship is a type of entrepreneurship, that shares similar sub-competencies such as discipline, innovation, risk-taking ability, etc. However, social entrepreneurship requires others, such as virtuosity, collaborative capacity, empathy, compassion, creative use of minimal resources, etc. Engineering professionals need to be aligned with these competencies, as they are involved with innovations, building infrastructure, and solving complex problems with a direct impact on communities. Texas A&M University annually promotes an academic hackathon called "Invent for the Planet" (IFTP), which brings together engineering students to seek solutions to proposed problems in 48 hours. During this period, students develop their projects according to the PBL methodology, actively seeking the necessary knowledge to present a prototype of the solution at the end of the process. Although the themes presented are varied, we observed a tendency for students to present solutions with a social bias, with, in some cases, the subsequent creation of startups to produce the developed artifacts. In this article, we present a success story, from a group from Brazilian universities that, during the IFTP, developed an electronic cane for the blind, which gave rise to a startup of products focused on accessibility. Through semi-structured interviews and focus groups with the participating students, we concluded that PBL was decisive in awakening specific sub-competencies for social entrepreneurship. Therefore, we propose the use of academic hackathons in engineering education as provocative tools for the development of competencies for social entrepreneurship.

**Keywords:** Social Entrepreneurship, Project-Based Learning; Academic Hackathon; Engineering Education.

## 1 Introduction

Since Schumpeter's seminal work was published in 1911, entrepreneurship has been a well-defined area within economic theory (Swedberg, 2000). However, social entrepreneurship was not initially central to this theory and was rarely covered in textbooks, magazines, and articles on entrepreneurship. Certo and Miller (2008) define social entrepreneurship as a process that recognizes, evaluates, and explores opportunities to generate social value, including the provision of basic needs such as food, health, and education. Social entrepreneurship has community goals and seeks profitability to reinvest in the organization (Steinerowski, Jack, & Farmer, 2008). It is most common in contexts with socioeconomic, environmental, and cultural challenges, offering sustainable solutions to social problems (Dacin et al., 2010; Nga & Shamuganathan, 2010).

Globally, social challenges often do not receive an effective response from governmental, non-governmental, and market institutions due to budget constraints, bureaucracy, and lack of capacity to innovate and adapt to the specific needs of communities. In this context, social entrepreneurs emerge to fill this gap, offering innovative solutions to problems such as poverty, inequality, lack of education, social exclusion, and environmental impacts. They apply viable business models, considering both social value and economic growth, taking an above-average risk in the conception and dissemination of social value, something that governments often avoid due to the pressure for immediate results. Furthermore, they can personalize their approaches, adapting them to the cultural, linguistic, and social particularities of each context. They identify flaws in society and turn them into business opportunities, recruiting and motivating others to their cause and building networks with essential people. They face obstacles and introduce their systems to manage their social businesses.

Social entrepreneurship shares some competencies common to entrepreneurship, such as discipline, innovation, and willingness to take risks. However, it requires additional skills, such as virtuosity, collaborative ability, empathy, compassion, and creative use of minimal resources, making a multidimensional analysis necessary in its study. Generally, social entrepreneurship competence is made up of five measurable dimensions or sub-competences: personal characteristics, leadership, social innovation, social value, and entrepreneurial management (Vázquez-Parra et al., 2021). Engineering professionals need to develop these competencies as they are involved in innovations, building infrastructure, and solving complex problems that directly impact communities.

There is a consensus that entrepreneurship is a skill that can be acquired, as it is possible to develop programs and courses that lead students to understand and structure contexts, as well as understand the stages in the evolution of entrepreneurship (Filion, 1999). Likewise, according to Freire (2001), through educational practice, students can perceive the social, political, and technological context of the reality of socially excluded people and understand the possibility of changing this situation through collective actions. As a teaching methodology, Freire proposes to address the problems faced by organizations and communities in which they operate, so that they can understand reality and, based on this, jointly propose conditions for social change.

In this context, universities are called upon to play a crucial role in promoting entrepreneurial behavior (Liguori and Winkler, 2020; Ndou et al., 2018; Secundo et al., 2021) through personalized education and incubator management to individuals who develop and share innovative ideas for social entrepreneurship (Solomon et al., 2019; Ratten and Jones, 2021; Secundo et al., 2021). However, several factors and challenges affect the effective development of competencies, knowledge, and entrepreneurial skills relevant to the creation of innovative ventures with social impact (Ndou et al., 2018; Lawrence et al., 2012; Vázquez-Parra et al., 2021).

In non-formal education, learning occurs interactively and intentionally, with objectives that are not previously established, but rather constructed through collective processes that generate social capital (Gohn, 2013; Willems, 2015). Social entrepreneurship exemplifies non-formal education, as it promotes the creation of a collective identity within a specific community; reconfigures the understanding of the world; prepares individuals to face life's challenges; helps to reinforce self-valuation and acquire practical knowledge, thus contributing to the development of social capital (Gohn, 2013; Iturrioz; Aragón; Narvaiza, 2015).

Training through project development is an effective strategy for developing these competencies. A widely used methodology is Problem/Project Based Learning (PBL), which is based on working on projects based on authentic problems. Students apply theory and knowledge acquired through research to projects, being responsible for their learning. Initially, they are presented with broad themes related to real-life issues and then they organize themselves into small groups to identify problems related to the proposed themes. Students search for solutions autonomously, prototype, test, and present their solutions to classmates and teachers. Mentor teachers continuously supervise these learning cycles, guiding and correcting routes, without offering ready-made solutions (GRAAF & KOLMOS, 2007; BENDER, 2012; KOKOTSAKY, MENZIES, & WIGGINS, 2016).

In the same line of thought, hackathons or bootcamps emerge as strategies for generating new ideas, products, or processes. These events begin with a challenge that requires the development of projects in a short period, often less than 48 hours. Despite its brevity, during the experience, all the fundamental steps for developing a PBL project are covered. Furthermore, hackathons are characterized by an emphasis on innovation, necessary due to competition and the rapid obsolescence of products.

Academic hackathons can be considered a subgroup of PBL activities, being called short-term PBL (d'Escoffier, d'Escoffier & Braga, 2022). The College of Engineering at Texas A&M University (TAMU) has been promoting short-term events focused on training in innovation and entrepreneurship for some time (Boehm, 2020). These events, known as "Aggies", aim to immerse students in a structured, intensive, and innovative design experience. In 2018, TAMU expanded this event model, which was already successful with its students, to a global scale, resulting in "Invent for the Planet" (IFTP), based on the "Aggies" model. IFTP challenges students from around the world to find solutions to problems provided by international institutions.

In this study, we investigated a group of students from Brazilian universities who, after winning an IFTP by proposing mobility devices for blind people, founded a startup focused on producing low-cost accessibility products. Through semi-structured interviews and focus groups, we sought to understand whether academic hackathons and PBL were decisive in awakening in students the demand for the development of sub-skills for social entrepreneurship. This data will be used to create educational strategies and initiatives designed to develop these skills and values among students.

# 2 Methodology

## 2.1 The case

A team made up of 6 students from the electrical and mechanical engineering course at the Federal University of Rio de Janeiro and CEFET/RJ won the 2019 IFTP with an accessibility project, made up of 2 artifacts that guide blind people on their daily commute. The first was a cap with sensors that allowed it to identify obstacles ahead. The other was a sensor that, when pointed in certain directions, allowed the detection of holes (electronic cane), both low-cost artifacts. After the event, the team decided to create a startup to commercialize that product. They later expanded their concept into an accessibility solutions company.

## 2.2 Data collection and analysis

The first stage of data collection was a virtual interview with one of the team members who played a leadership role in the process. During the interview, we seek to learn about the experience from this student's point of view. Based on the information provided to him, a second stage was scheduled, which consisted of a virtual focus group with all startup participants. To resolve some issues, individual virtual interviews were carried out with three members of the group.

The questions raised in the focus group were organized based on the information given in the interview using a semi-structured question model. The use of this methodology aimed to obtain a collective mental reconstruction of the process the students went through. During this process, each student could talk about their experience in the process and compare it with that of their peers. This information collection technique allows for a more reliable reconstruction of the facts, as it is shared by everyone who lived the experience. Individual meetings were conducted with specific questions to the members to clarify details that were not clear in the focus group.

The reports were analyzed qualitatively (Morgan, 1997), using a methodological approach inspired by content analysis, to identify indicators (quantitative or not) that would allow inferences about the conditions of production and reception of these messages (inferred variables) (Bardin, 1977). Based on this analysis, the information was organized into analysis categories.

At all stages, the students participated voluntarily.

# 3 Results

Participation in IFTP was encouraged by its teachers, with no immediate interest. At first, they believed that they would participate in some type of training activity in which their technical skills would be required. The entrepreneurial perspective or the creation of a startup never crossed their minds, although the topic of entrepreneurship arouses some curiosity. In essence, they attended the event out of respect for the teachers. Therefore, there was no contact with entrepreneurial or innovation training during the course.

The group's choice of the theme "Increased quality of life" was random, as the mother of one of the members worked with children with special needs. During the interview, we realized that there was a desire to produce something that would reach the target audience, without any idea of the role of entrepreneurship in the process. They developed two interdependent accessories that guide blind people on their daily journey. The first was a cap with sensors that allowed it to identify obstacles ahead. The other was a sensor that, when pointed in certain directions, allowed the detection of holes (electronic cane). The idea for creating the product arose from the team members' ability to use sensors.

*"...our prototype was not to cure blindness, but to improve the quality of life of these people."* (Student 1, mechanical engineering).

The victory in the regional section signaled the product's usefulness and practicality. Confident in the quality of the project, the group took advantage of the one month until the trip to TAMU to participate in the final, to improve the prototype, making it more efficient and visually more attractive. They also tested the prototype with a blind person. At this point, they had time to delve deeper into the topic and, as a consequence, they began to realize the social importance of the product, as we can see in the statement below:

*"When we saw people with disabilities using our equipment, which we had produced quickly, we were very happy and saw that the product worked. We had managed to improve the life of that disabled person..."* (Student 4, mechanical engineering).

By becoming IFTP champions, they felt confident in the quality of the product and recognized the possibility of its commercialization. Thus, the group decided that they wanted to set up their own company, despite their insecurity about the venture:

*"Until now we didn't have any ideas and, can we do something beyond that?..."* (Student 3, mechanical engineering).

However, despite all the difficulties encountered, including having to initially maintain and manage the business with its resources, the group did not give up and, with the proceeds from the sale of the first units that were being sold, they created other low-cost products aimed at accessibility, such as a card with data about the person with a disability that can be accessed by anyone who wants to obtain information about the person, without the need to fill out forms or speak orally, and a Tag with the same functions as the card.

According to the students' speech, it is clear that the experience at the event stimulated thinking about social entrepreneurship, making them look beyond what traditional training can offer:

*"It's not worth going to college just to get a good grade, close the academy, and get a diploma at the end. If you do that, you won't add anything... I don't think it adds much to what you can build."* (Student 2, electrical engineering).

*"We only managed to do it because there was all the organization of the event..."* (Student 4, mechanical engineering).

## 4 Discussion

Entrepreneurial education is a crucial component for new markets. Encouraging young people to start their businesses is essential for the economic growth of the country and institutions. Students who participate in courses focused on entrepreneurship are more likely to engage in activities and ideas for new ventures (Bergmann, 2018). Furthermore, entrepreneurial education is one of the missions of education, alongside teaching, research, and economic development through business technology or the creation of companies by students and teachers (García et al., 2017).

We currently recognize that education plays a central and catalytic role in social change, especially in areas where social problems such as poverty or social exclusion are evident. This understanding has led to the emergence of educational initiatives aimed at addressing the causes of these problems, making both formal and non-formal education fertile ground for the creation and dissemination of innovative social initiatives. Meaningful learning is fundamental, as it is through it that individuals develop and mobilize new attitudes (Parente, 2014).

According to García-Gonzales & Ramírez-Montoya (2020), social entrepreneurship education focuses on personal development, identifying opportunities, and searching for solutions to social or environmental problems. Engineers, as producers of innovation, are fundamental players in contributing to social entrepreneurship, hence the importance of developing this sub-competence in engineering courses.

Given this, the creation of academic hackathons is a good idea for using non-formal education to encourage innovation and entrepreneurship. However, although there are hundreds of this hackathon model taking place every year in several universities around the world (DEVPOST, 2023), few works arising from these events become startups. Hence the importance of studying the case presented here.

The IFTP winning team had the opportunity to develop a low-cost product aimed at people with special needs. During the event, there was a need for theoretical deepening not only for the development of the artifact, with the consequent development of technical skills (hard skills) but also for the search for knowledge that justified the creation of the product. At this point, skills at a behavioral level (soft skills) could be developed, including the sub-competence of social entrepreneurship. This can be confirmed by the fact that, in the beginning, although they had casually had the idea of producing a device for social purposes, the idea of starting a business with this product never crossed the students' minds.

How the IFTP event is conducted can be considered as a short-term PBL, by aligning with its phases. It is well-studied that PBL is capable of developing specific competencies in students (Kolmos & Fink, 2004). In our study, this became clear when the students stated that they started at the event with no prospects and, when they left, they opened a startup focused on accessibility.

Therefore, the PBL methodology associated with the dynamics of an academic hackathon is capable of awakening in students not only awareness of the importance of developing certain skills but also the desire to become entrepreneurs.

Therefore, if we implement hackathons organized in PBL format in educational environments, with themes that seek innovative solutions to social, environmental, and cultural problems, we can have a generation prone to social entrepreneurship, contributing to the creation of a fairer, more inclusive, and sustainable world.

We are aware that the period of a hackathon, in our case 48 hours, is limited for the complete development of skills. However, it is capable of stimulating students in their progress, as evidenced by students' comments, when they realize the effectiveness of the prototype in improving the quality of life of a blind person, or when they recognize the role of the engineer in contributing to the construction of something meaningful to society.

# 5 Conclusion

The case presented demonstrates that skills for social entrepreneurship can be developed through non-formal educational initiatives in the training of engineers. IFTP is an international event led by Texas A&M that brings together several institutions, whose main role is to train students in innovation and entrepreneurship. This event was able to awaken a vision of social entrepreneurship in a group of students so this group opened a startup focused on low-cost products for accessibility.

We also concluded that the PBL methodology was fundamental to success, given that students when guided through the PBL phases, were able to identify problems within the reality around them, seek solutions for them, and produce a functional prototype. Also, when they felt the need to look for indications that justified their product, they had access to information related to previously unnoticed scenarios, expanding their vision of society's problems.

Therefore, we propose the use of academic hackathons in PBL format in engineering education as provocative tools for the development of competencies for social entrepreneurship.

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# Risk Response Actions in the preparation of Undergraduate Final Project Reports – UFPR (Undergraduate Thesis) when using Project-Based Learning

José C. Pereira[1], Flávio Almeida[2]

[1] Master Program in Engineering Department, UCP (Universidade Católica de Petrópolis), Rio de Janeiro, Brasil
[2] Master in Mechanical Engineering – Fiocruz (Oswaldo Cruz Foundation) - Rio de Janeiro, Brasil

E-mail: josecristiano.pereira@ucp.br; flavio.almeida@fiocruz.br

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**Abstract**

Project-based learning (PBL) has gained increasing prominence in engineering education because it enriches students' professional knowledge. Despite the growing interest in implementing PBL in engineering education, a comprehensive literature review has identified a significant gap: specific studies addressing risk response actions in preparing undergraduate theses using PBL have not been found. A paper titled "Proposal of Method for Risk Assessment of Failure in Undergraduate Final Project Report – UFPR (Undergraduate Thesis) when using Project-Based Learning" was presented at the PAEE/ALE'2023 international conference on active learning in engineering education. However, the study did not present the required response actions for identified risks. This study introduces guidance with risk response actions to manage the adequate preparation of undergraduate theses in engineering. A case study focused on resolving real-world problems local companies face within a specific region, with PBL as a supporting framework. This case study complements the findings presented at PAEE/ALE'2023 with tables outlining detailed actions to be taken during different processes to mitigate risks and prevent failure. The study concludes that the proposed actions can potentially optimize resources and, consequently, enhance the overall quality of undergraduate theses. Furthermore, this research lays the groundwork for future endeavors in engineering education, providing a framework to streamline and enhance the undergraduate thesis experience for students, professors, and decision-makers involved in thesis supervision.

**Keywords:** Active Learning; Engineering Education; Project-Based Learning - PBL; Undergraduate Thesis

## 1 Introduction

In engineering education, student-centered teaching methods, mainly Project-Based Learning (PBL), have gained widespread adoption. Despite its popularity, universities often grapple with unforeseen challenges while implementing PBL and may revert to conventional teaching approaches (Henderson, 2012). Hence, it becomes imperative to identify, articulate, and address risk factors directly influencing the preparation of undergraduate theses. Notably, the existing literature in engineering education has shown a deficiency in addressing the risks associated with undergraduate thesis failure, with even less attention given to risk responses. In response to this gap, the authors conducted a literature review to pinpoint key risk factors in preparing undergraduate theses. Recognizing these risks and understanding how to respond effectively can enhance success rates and establish a sustainable teaching methodology within universities. Current studies on the use of PBL in higher education are the one by Kaeedi et al. (2023), which compared the effectiveness of problem-based learning (PBL) and lecture-based learning (LBL) methods to teaching research methods by mixed-methods approach in an explanatory sequential design. Lin et al. (2023) studied the PBL teaching method. They explored the new trend of reforming teaching thinking, teaching mode, and teaching means of the introductory courses of engineering majors to cultivate students' innovative thinking and improve their innovative ability. Para-González et al. (2023) empirically examined whether PBL improves apprenticeship abilities' development and promotes Students' subject overcoming and their Professional success using data from 65 Spanish University students. Leatemia et al. 's (2023) study aimed to identify teacher profiles that would reveal teachers' specific educational needs and investigate the relationship between these profiles and the PBL training previously received. However, a gap exists in understanding how PBL influences the quality and effectiveness of final project reports, a crucial component of undergraduate research. The study contributes to the literature by assessing the risks associated with the preparation of undergraduate thesis preparation in engineering education. The diversity of identified risk factors underscores the intricacy of the process. Addressing most of these risks necessitates appropriate responses, justifying the need for the proposed study. Projects may falter without identifying and adequately mitigating risks, depriving students, professors, and partner organizations of anticipated benefits. The proposed method can potentially enhance professors' and students' skills and practices, ultimately elevating the quality of undergraduate theses. It is crucial to note that the study focuses explicitly on PBL, which involves collaboration with external companies. Completing undergraduate thesis projects can significantly mitigate business risks and improve quality and organizational safety. The existing literature review revealed a lack of studies comprehensively addressing risk assessment and its impacts on undergraduate theses. This study identifies risks and proposes a method to address them. The research questions guiding this study revolve around:

1 – What are the risks factors and actions to avoid or mitigate risks in PBL conducted in local companies during undergraduate thesis preparation?

2 – How can professors and students manage undergraduate thesis processes digitally and applying different learning theories?

The paper is organized into five sections: the first introduces the context and problem, the second presents studies about PBL in Undergraduate Final Projects. The third the Theoretical Learning theories applied in 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 PBL in Undergraduate Final Projects

Studies about PBL highlight its effectiveness in promoting active learning, critical thinking, problem-solving, collaboration, and other skills essential for academic, professional, and personal success. The importance of PBL is recognized in various educational settings to prepare students for the challenges of the 21st century.

Previous significant studies about PBL are presented herein. Palmer and W. Hall (2011) presented a PBL offering in engineering at Griffith University in Australia, observing that students generally enjoyed the experience, with aspects needing improvement listed and documented. Du et al. (2013) developed a framework of change in educational culture for sustainability using a PBL methodology, inspiring curriculum design for sustainability education. García-Martín and Pérez-Martínez (2017) presented a method to guide teachers using PBL principles and instructional design models, focusing on fundamental issues in active learning. Marques (2018) proposed a formative monitoring method to enhance students' individual and team performance, with results indicating that PBL effectively enhanced the learning experience. Setiawan (2019) conducted a study on implementing PBL, explicitly focusing on opportunities and challenges, where students chose their topics and explained their problem-solving approaches. Moliner et al. (2019) described the experience of using PBL in Materials Science courses conducted by Spanish universities, analyzing the perceptions of students and lecturers in the PBL process. Schneider (2020) used PBL to enhance student engagement. Daun (2016) discussed results from the application of such a course design in a graduate setting, indicating that PBL techniques foster different teaching goals in graduate and undergraduate settings. The study by Bhaskar et al. (2023) has identified and prioritized four main inhibiting factors. Institutional-level factors have secured the highest rank, followed by technological, operational, and personal-level factors. Merola et al. 's (2022) study explores how international student satisfaction is affected by some aspects of the learning and experience. Nguyen et al. (2022) provided a conceptual structure and charted the evolution of human resource management research in higher education from 1966 to 2019. Sousa et al. (2022) analyzed the organizational culture of two higher education institutions, one from Portugal and another from Spain. Previous studies show that PBL is a teaching method involving students investigating and solving complex, real-world problems. Various factors can influence the design of PBL, and educators need to consider these factors to create effective and engaging learning experiences. By carefully considering these factors, educators can create PBL experiences that are engaging, meaningful, and aligned with educational objectives. The flexibility of the PBL method allows for customization to suit the unique needs of students and the learning environment. Pereira et al (2022) stated that PBL projects conducted in collaboration with local companies involve students working on real-world problems and applying theoretical knowledge to practical situations.

# 3 Theoretical Learning theories applied in Undergraduate Final Projects

Final project reports play a crucial role in undergraduate education by providing students with valuable research experience, developing essential skills, and preparing them for future academic and professional pursuits. Additionally, they benefit educational institutions by promoting deeper learning, assessing student learning outcomes, and fostering a research culture. Haritha and Rao (2024) present the theory on experiential learning and Kolb's Experiential Learning Cycle, which emphasizes the importance of the learning cycle - concrete experience, reflective observation, abstract conceptualization, and active experimentation. Final project reports can provide a platform for students to reflect on their experiences, develop abstract concepts from their research, and plan future actions based on their findings. Rohman et al. (2024) studied Piaget's Theory of Cognitive Development, which suggests that learners actively construct their understanding through interaction with experiences and the environment. Final project reports allow students to solidify their knowledge by organizing their research findings and constructing a coherent argument. Ott (2024) describes Bandura's Social Learning Theory, which highlights the importance of self-efficacy in learning. Final project reports can foster self-directed learning by requiring students to take ownership of their research process, make independent decisions, and manage their time effectively. Rosser and Sole (2024) studied the Problem-Solving and Critical Thinking proposed by Schön's Reflective Practice, which emphasizes the importance of reflection in professional practice. Final project reports encourage students to critically evaluate their research process, identify challenges, and propose solutions. Ilhami (2024) studied Bloom's Taxonomy, which categorizes learning objectives. Final project reports serve as a cornerstone of a well-rounded undergraduate education. By offering students a platform for experiential learning (Haritha & Rao, 2024), knowledge solidification (Rohman et al., 2024), and self-directed learning (Ott, 2024), these projects equip graduates with the research skills and critical thinking necessary for future success. Furthermore, final project reports benefit institutions by fostering a research culture (Rosser & Sole, 2024) and providing a comprehensive assessment tool that aligns with Bloom's Taxonomy (Ilhami, 2024). Ultimately, final project reports represent a valuable bridge between theory and practice, preparing students for lifelong learning and professional endeavors.

# 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.

## 4.1 Population and Sample

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.

### 4.2 Instruments and Tools

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.

### 4.3 Data Collection

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.

### 4.4 Data Analysis & Actions

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 the chart with the process's groups.

### 5.1 Processes Groups

The Processes Groups involved in preparing the Undergraduate Final Project Reports are presented in Figure 1. 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.

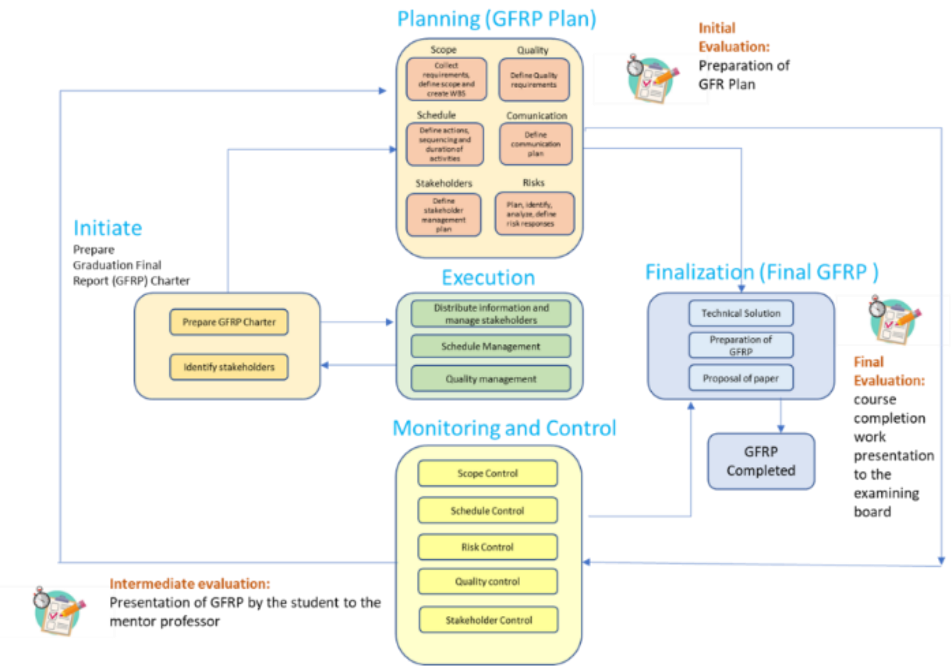


Figure 1. Process Management Groups

## 5.2 Processes Details, Risks, and Responses

### 5.2.1 Initiation Processes Group

Tables 2 and 3 show the processes that are part of the initiation group, the benefits/success factors, what could go wrong, the consequences and actions to avoid or mitigate risks. Table 2 shows that preparing a charter for an undergraduate final project report or thesis is vital because it helps to attain the benefits described in the second column. The third column shows the risk factors leading to process failure. The last column shows the actions to avoid or mitigate risks.

Table 2. Process – Prepare Charter

| **Process** | **Benefits / Success Factors** | **Risks Factors** | **Actions to avoid or mitigate risks** |
|---|---|---|---|
| Prepare Charter | Define the scope and goals of the project. Set expectations for all stakeholders. Help the student to stay on track. Provide a framework for assessing the success of the project.<br>In addition to these benefits, a charter can also help identify and mitigate risks and improve communication and collaboration. Enhance the quality of the final project report or thesis. | Unclear Objectives. Lack of Stakeholder Involvement. Inadequate Research. Poorly Defined Timeline. Insufficient Resources. Scope Creep. Ineffective Communication. Inadequate Planning. Methodology Issues. Procrastination. Technical Challenges. Data Quality. Writer's Block. Stress and Burnout. | Start with a well-defined project charter. Communicate effectively. Establish a realistic project timeline. Conduct thorough research. Stay organized. |

Table 3 shows the process of identifying stakeholders. The second column shows the benefits of preparing an undergraduate final project report or thesis. Students can identify stakeholders by brainstorming a list of all the individuals and organizations that could be affected by or interested in their project. They can also consult with their supervisor or other faculty members for guidance. Once stakeholders have been identified, students should develop a plan for communicating with them and keeping them updated on the progress of their project. This may involve regular meetings, email updates, or other forms of communication. By identifying and communicating with stakeholders, students can ensure that their final project report or thesis is relevant, helpful, and high-quality. The third column shows the risk factors. The last column shows the actions to avoid or mitigate risks.

Table 3. Process – Identify stakeholders.

| Process | Benefits / Success Factors | Risks factors | Actions to avoid or mitigate risks |
|---|---|---|---|
| **Identify stakeholders** | Identifying stakeholders is essential in preparing an undergraduate final project report or thesis for several reasons: Ensure that the project meets the needs of all stakeholders and secure support and resources for the project. Manage expectations and communication. Gain valuable feedback. Create a network of contacts. | Incomplete Stakeholder Identification. Misunderstanding Stakeholder Needs. Conflicting Stakeholder Interests. Lack of Communication. Failure to Engage Key Stakeholders. Ethical Concerns, Changes in Stakeholder Composition. Overburdening Stakeholders. Lack of Clear Roles and Responsibilities. Resistance and Opposition. | Have a well-defined process. Effective communication strategies. A proactive approach. Regularly update stakeholders. Seek their input when appropriate. Be prepared to adapt project as needed. Consider involving an academic advisor. |

### 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 details and importance, what could go wrong, the consequences and actions to avoid or mitigate issues.

Table 4 shows the process scope planning. The scope of an undergraduate final project report or thesis plays a crucial role in planning, offering several benefits, as listed in the second column. A good scope is crucial for planning an undergraduate final project report or thesis. It ensures that research is focused, feasible, and relevant and aids in time management and resource allocation. By defining a clear scope, the stage for a well-structured, high-quality, and impactful project is set to align with the academic and career goals. The third column shows that issues may arise if it's not done carefully. The last column shows the actions to avoid or mitigate risks.

Table 4. Process – Scope Planning

| Process | Benefits / Success Factors | Risk Factors | Actions to avoid or mitigate risks |
|---|---|---|---|
| **Scope Planning** | Clarity and Focus. Feasibility. Time Management. Resource Allocation. Relevance. Quality and Depth of Research. Manageable Workload. Reader Engagement. Alignment with Objectives. Advisors' Guidance. Ethical Considerations | Overambitious Scope. Unclear Objectives. Inadequate Research. Lack of Stakeholder Involvement. Poorly Defined Deliverables. Scope Creep. Insufficient Time and Resource Allocation. Technological Challenges. Poor Risk Management. Inadequate Communication. Lack of clear communication. | 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. |

Table 5 shows the process of Quality planning. The second column from the table illustrates the indispensability and benefits of delineating quality requirements in the strategic planning of an undergraduate final project report or thesis for various reasons. Defining quality requirements when planning an undergraduate final project report or thesis is crucial for ensuring the work's quality, professionalism, and credibility. It provides a framework for maintaining consistency, minimizing errors, and meeting academic standards. Adhering to these requirements enhances the research's overall quality and impact, benefiting the academic journey and future career prospects. The third column illustrates various potential challenges associated with preparing a scope for an undergraduate final project report or thesis and the common pitfalls to be mindful of. The fourth column shows the actions to avoid or mitigate risks.

Table 5. Process – Quality Planning

| Process | Benefits / Success Factors | Risk Factors | Actions to avoid or mitigate risks |
|---|---|---|---|
| Quality Planning | Clarity and Expectations, Quality Assurance, Alignment with Academic Standards, Professionalism, Objective Evaluation, Consistency, Reduction of Errors, Stakeholder Expectations, Credibility and Impact, Personal and Professional Development, Time, and Resource Management | Scope Too Broad, Lack of Clarity, Scope Creep, Overly Ambitious Goals, Lack of Relevance, Insufficient Research Opportunities, Difficulty in Finding Literature, Inadequate Consultation, Ethical Dilemmas, Inadequate Resources, Revisions and Delays | 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. |

Table 6 shows the process of Schedule Planning. The second column illustrates the benefits of establishing a robust schedule in planning an undergraduate final project report or thesis and the benefits. The third column presents an overview of challenges and potential issues that may arise when formulating a schedule for planning an undergraduate final project report or thesis. The last column shows how to address these potential issues.

Table 6. Process – Schedule Planning

| **Process** | **Benefits / Success Factors** | **Risk Factors** | **Actions to avoid or mitigate risks** |
|---|---|---|---|
| **Schedule Planning** | Time Management, Deadline Adherence Task Organization, Resource Allocation, Proactive Problem Solving, Consistency and Productivity, Stress Reduction, Balancing Other Responsibilities, Feedback Incorporation, Revision and Editing, Adequate Rest and Well-Being, Long-Term Planning | Underestimating Time Requirements, Overly Optimistic Planning, Inadequate Flexibility, Scope Creep, Procrastination, Neglecting Revision and Editing, Overloading Other Responsibilities, Lack of Contingency Planning, Burnout, Failure to Seek Guidance, Inconsistent Progress Tracking, Lack of Prioritization | 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. |

Table 7 shows the process of Communication Planning. The second column illustrates effective communication's paramount significance and benefits in planning an undergraduate final project report or thesis. The third column illustrates several communication challenges and issues that may arise when planning for an undergraduate final project report or thesis. The last column shows the actions to avoid or mitigate risks.

Table 7. Process – Communication Planning

| **Process** | **Benefits / Success Factors** | **Risk Factors** | **Actions to avoid or mitigate risks** |
|---|---|---|---|
| **Communication Planning** | Clarity of Objectives, Feedback and Guidance, Problem-Solving, Resource Allocation, Time Management, Ethical Considerations, Collaboration, Adherence to Guidelines, Accountability, Conflict Resolution, Preparation for Defense, Networking and Future Opportunities | Misunderstandings, Lack of Guidance, Inconsistent Feedback, Lack of Transparency, Overdependence on Advisors, Ineffective Collaboration, Unresolved Conflicts, Neglecting Ethical Considerations, Limited Resource Access, Inadequate Time Management, Failure to Adhere to Guidelines, Overloading Advisors, Ineffective Presentation | Establish clear lines of communication. Maintain open, regular, and respectful communication. Seek feedback and address any issues. Effective communication. |

Table 8 shows the process of Stakeholder Planning. The second column illustrates the essentiality and benefits of stakeholder definition in planning an undergraduate final project report or thesis. The third column illustrates that various challenges and issues accompany the essential task of defining stakeholders in planning an undergraduate final project report or thesis. The last column shows the actions to avoid or mitigate risks.

Table 8. Process – Stakeholder Planning

| Process | Benefits / Success Factors | Risk Factors | Actions to avoid or mitigate risks |
|---|---|---|---|
| **Stakeholders Planning** | Clear Objectives, Expectation Management, Feedback and Guidance, Resource Allocation, Accountability, Ethical Considerations, Collaboration, Conflict Resolution, Communication, Long-Term Impact, Networking and Future Opportunities | Incomplete Stakeholder Identification, Misalignment of Expectations, Overestimation of Stakeholder Involvement, Conflict or Disagreements, Inadequate Resource Contribution, Ethical Dilemmas, Lack of Communication, Scope Creep, Overloading Stakeholders, Loss of Stakeholder Interest | Conduct thorough stakeholder analysis. Engage in effective communication. Manage expectations proactively. Clearly define stakeholder roles and responsibilities. Address conflicts and ethical concerns. Regularly update and involve stakeholders in the project's progress. |

Table 9 shows the process of Risk Planning. The second column illustrates the benefits of delineating risks in planning an undergraduate final project report or thesis. The third column shows several challenges and issues when defining risks in planning an undergraduate final project report or thesis. Being aware of potential pitfalls is essential to manage and mitigate risks effectively. The last column shows the actions to avoid or mitigate risks.

Table 9. Process – Risk Planning

| Process | Benefits / Success Factors | Risk Factors | Actions to avoid or mitigate risks |
|---|---|---|---|
| **Risks Planning** | Risk Awareness, Risk Mitigation, Time Management, Resource Allocation, Quality Control, Project Confidence, Stakeholder, Communication, Ethical Considerations, Adaptability, Conflict Resolution, Learning Opportunity, Career Development | Incomplete Risk Identification, Overemphasis on Minor Risks, Misclassification of Risks, Failure to Prioritize Risks, Lack of Detailed Mitigation Strategies, Neglecting Ethical Risks, Overreliance on Existing Plans, Ineffective Communication, Neglecting Long-Term Risks, Scope Creep, Inadequate Moni | 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 |

### 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 the process of distributing information and managing stakeholders. The second column shows the benefits of distributing information and managing stakeholders when preparing Undergraduate Final Project reports. The third column shows that distributing information and managing stakeholders during the preparation of Undergraduate Final Project reports can be complex, and various challenges may arise. The last column shows the actions to avoid or mitigate risks.

Table 10. Process – Distribute information and manage stakeholders

| Process | Benefits / Success Factors | Risk Factors | Actions to avoid or mitigate risks |
|---|---|---|---|
| **Distribute information and manage stakeholders.** | Communication and Transparency. Feedback and Improvement. Resource Allocation. Risk Management. Accountability. Support and Motivation, Professional Development | Poor Communication, Incomplete or Inaccurate Information, Ineffective Stakeholder Engagement, Unclear Project Objectives, Scope Creep, Problems with Team Collaboration, Technical Issues, Inadequate Risk Management | Establish clear communication channels. Define roles and responsibilities. Regularly update stakeholders. Have a well-defined project plan. |

Table 11 shows the process Schedule Management. The second column shows the importance of effective schedule management in preparing Undergraduate Final Project reports. The third column presents various challenges and pitfalls in managing schedules while preparing Undergraduate Final Project reports. The last column shows the actions to avoid or mitigate risks.

Table 11. Process – Schedule Management

| Process | Benefits / Success Factors | Risk Factors | Actions to avoid or mitigate risks |
|---|---|---|---|
| **Schedule Management** | Time Efficiency. Task Prioritization, Quality of Work, Revision and Editing, Stress Reduction, Avoiding Procrastination, Coordination with Advisors and Stakeholders, Professionalism, Learning Time Management Skills, Adaptability | Underestimating Time Requirements, Overloading the Schedule, Unforeseen Delays, Lack of Contingency Planning, Procrastination, Poor Communication with Advisors, Scope Creep, Ignoring Feedback and Revisions, Inadequate Time for Reflection, Health and Well-being | Regularly reassess and adjust your schedule. Communicate effectively with project stakeholders. Practice good time management habits. Flexibility and adaptability |

Table 12 shows the process of Quality Management. The second column shows that quality management is crucial to preparing Undergraduate Final Project reports. Quality management is critical when preparing undergraduate final project reports, as it helps develop essential skills, demonstrates academic rigor, and establishes credibility. It sets the stage for students to succeed academically and professionally. The third column shows several challenges and issues that may arise when managing quality while preparing Undergraduate Final Project reports. It is essential to be aware of these potential pitfalls to address them effectively. The last column shows the actions to avoid or mitigate risks.

Table 12. Process – Quality Management

| Process | Benefits / Success Factors | Risk Factors | Actions to avoid or mitigate risks |
|---|---|---|---|
| **Quality Management** | Demonstrates Academic Rigor, Ensures Accuracy and Reliability, Enhances Credibility, Prepares for Future Academic Pursuits, Promotes Accountability, Encourages Continuous Improvement, Prepares for Professional Environments, Facilitates Evaluation | Insufficient Planning, Lack of Clear Objectives, Inadequate Research: Poor Data Collection and Analysis, Plagiarism and Academic Integrity Issues, Ineffective Communication, Limited Faculty Guidance, Technology Issues, Time Management Challenges, Lack of Revision | Provide comprehensive guidance. Clear expectations. Well-defined objectives. Effective communication |

### 5.2.4 Monitoring Processes Group

Monitoring and controlling the planning and execution processes while preparing Undergraduate Final Project reports are crucial aspects of project management. These activities help ensure that the project stays on track, meets its objectives, and is completed successfully. Here are some key reasons why monitoring and control are essential: 1 - Progress Tracking, 2 - Risk Management, 3 - Resource Management, 4 - Quality Assurance, 5 - Adherence to Scope, 6 - Communication and Collaboration, 7 - Decision Making, 8 - Client or Advisor Satisfaction, 9 - Identifying and Addressing Bottlenecks, 10 - Learning and Improvement. Reflecting on the successes and challenges encountered during the project can identify future project improvement areas.

Monitoring and controlling the planning and execution processes are integral to the success of Undergraduate Final Project reports. These processes help maintain project quality, manage resources effectively, and ensure the project stays aligned with its goals and objectives. Regular assessments and adjustments contribute to a more successful and well-executed final project.

#### 5.2.5 Closure Processes Group

Closure or finalization processes are crucial during the preparation of Undergraduate Final Project reports as they mark the formal conclusion of the project and encompass several essential aspects that contribute to the project's overall success. Here are key reasons why closure processes are essential: 1 - Documentation Completion, 2 - Review and Evaluation, 3 - Lessons Learned, 4 - Feedback and Evaluation from Stakeholders, 5 - Formal Presentation or defense, Client or Advisor Satisfaction, 7 - Archiving and Record Keeping, 8 - Ethical Considerations, 9 - Transition to Next Steps and 10 - Celebration and Recognition. Closure processes are integral to the successful completion of Undergraduate Final Project reports. They ensure the project is well-documented and thoroughly evaluated. The closure also allows celebrating achievements and transitioning to the next academic or professional journey phase.

### 5.3 Digital Process

Records generated in the execution of the processes are uploaded into a database within specific folders. Implementing a digital process can significantly enhance the management of Undergraduate Final Project report preparation. Implementing a digital process improves efficiency and prepares students for a digital work environment, where collaboration and effective use of digital tools are increasingly essential skills. Additionally, it can simplify administrative tasks for faculty members involved in project supervision and Evaluation. The combination of digital thesis management tools with various learning theories, as shown in the literature review, allow professors the creation of engaging and effective learning environment for undergraduate students. This approach facilitates collaboration, promotes independent learning, and empowers students to take ownership of their research process.

## 6 Discussion of Results

As articulated in the introductory section, the study not only introduced but also delineated a comprehensive process map designed for executing PBL projects in collaboration with local companies within the context of undergraduate thesis preparation. This structured method incorporates project management principles, serving as a dynamic framework to address practical challenges encountered by local companies during the undergraduate thesis preparation phase. The tables listing the risks and actions show that by proactively identifying risks and implementing appropriate actions, students can significantly improve the effectiveness of their final project reports. This proactive approach leads to higher quality research, reduces stress, and fosters a sense of accomplishment. Based on the theoretical background presented in the literature review, final project reports can help students develop higher-order thinking skills like analysis, synthesis, and Evaluation – all crucial for effective problem-solving. Final project reports develop research skills and emphasize how final project reports can equip students with essential research skills like data collection, analysis, and communication. It prepares students for graduate studies or research-intensive careers. It is a valuable assessment tool, allowing students to showcase their learning and understanding of course concepts. The proposed approach recognizes the symbiotic relationship between academic endeavors and real-world problem-solving, aiming to foster a mutually beneficial collaboration between educational institutions and local industry stakeholders. Furthermore, the study elucidates by a charter, showing groups of processes and how applying project management principles enhances the efficacy of the proposed PBL method. The identification of risks and the implementation of actions in the preparation of final project reports can significantly improve their effectiveness. By emphasizing aspects such as scope definition, objective setting, meticulous planning, resource management, and effective communication, the project management framework ensures a systematic and well-organized approach to undergraduate thesis preparation. This not only facilitates the seamless execution of projects but also contributes to developing critical project management skills among students. The proposed digital process envisions professors as facilitators and guides, orienting students, aiding in project scoping, providing mentorship, and ensuring ethical considerations are upheld. Additionally, professors play a pivotal role in structuring timelines, offering valuable feedback, and overseeing the culmination of the thesis through defence preparation and final submission.

# 7 Conclusion

Applying the proposed method in preparing the undergraduate thesis report process fills a gap in the literature since no previous work has dealt with this subject. In response to the first question "What are the risks and actions to avoid or mitigate risks in PBL conducted in local companies during undergraduate thesis preparation?" The risks and the actions were presented in tables for each phase and the conclusion is that foreseeing roadblocks and taking preventative measures can significantly elevate the impact of final project reports. This proactive strategy not only yields higher quality research, but also reduces student stress and fosters a sense of accomplishment. In response to the second question "How can professors and students manage undergraduate thesis processes digitally and applying different learning theories?" The results show that by combining a digital management process and applying learning theories, professors can create an engaging and effective learning environment for undergraduate students. This approach facilitates collaboration, promotes independent learning, and empowers students to take ownership of their research process. Managing the undergraduate thesis process requires a structured approach involving professors and students. By following the proposed digital method, professors and students can contribute to a well-structured and successful undergraduate thesis process. Regular communication, early planning, and a focus on feedback and improvement are critical elements in managing the thesis process effectively. The proposed method revealed some crucial results, thus contributing to previous studies on the subject and may help overcome some of the challenges of professors, students, and other professionals looking for quality education. The study was conducted based on the experience and knowledge of professors and students. The present study is believed to augment the knowledge of engineering school professors, students, and coordinators and help use the proposed process. As the Introduction Section explains, several papers have been published addressing PBL use in different domains in recent years. However, no previous study related to identifying risks in undergraduate thesis could be found. Notably, this paper proposes an optimized approach that could be used in any university or teaching organization. This proposed method can guide universities in the traditional teaching process to achieve quality improvement. That helps to impact results, representing considerable teaching gains. The proposed method, enhanced by improved communication, enables any university to increase efficiency in education. This study shows evidence that the quality of the process is affected by several factors, some of which can compromise the reliability of the teaching institution. In this regard, process analysis played a crucial role in understanding and implementing actions to improve it. Scope for future research: This study opened some new research avenues. Opportunities for other case studies are abundant. They could be related to a broader application of risk analysis of undergraduate thesis reports in specific cases, enhancing the current method and reducing the risk of failures.

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# Enhancing Understanding and Performance in Competency-Based Education: A Visual Management Approach

Thiago Vidal Pereira de Sá[1], Marcelo Carneiro Gonçalves[2], João Mello da Silva[3]

[1] Department of Industrial Engineering, Pontifical Catholic University of Paraná (PUCPR), Curitiba, Brazil.
[2] Department of Industrial Engineering, University of Brasilia (UNB), Brasília, Brazil.
[3] Graduate Program in Applied Computing, University of Brasilia (UNB), Brasília, Brazil.

Email: thiagovpds68@gmail.com, marcelo.goncalves@unb.br, joao.mellos@gmail.com.

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**Abstract**

The competency-based education model has gained prominence in Brazil in recent decades, largely due to the actions of the Ministry of Education, which replaced the old higher education model based on minimum curricula with the National Curricular Guidelines for Higher Education (DNC). This transition presents challenges, particularly in terms of visually managing the new system, crucial for students to understand its structure and track their performance. This work proposes the application of visual management in competency-based education, aiming to facilitate understanding of the curriculum structure and performance tracking by competencies throughout the course, as opposed to focusing solely on disciplines. To achieve this, methodologies such as knowledge management and agile practices were adopted, along with tools such as brainstorming and value proposition canvas. The solution was implemented using the virtual platform Frigma, resulting in positive outcomes evaluated with stakeholders at a Brazilian higher education institution, with significant improvements in performance indicators. It is concluded, therefore, that the adoption of visual tools represents an effective approach to enhancing students' understanding of the competency-based education model.

**Keywords:** Competency-based education; Visual management; Curriculum structure; Performance tracking.

## 1 Introduction

Competence, originally a term rooted in legal discourse, has evolved significantly over time. Initially denoting the authority of a public body to adjudicate certain matters, its scope broadened as scholars like Harvard University psychologist David C. McClelland redefined it. McClelland (1973) advocated for assessments measuring not just cognitive abilities but also skills and personality traits. This led to a broader understanding of competence as the amalgamation of knowledge, skills, and attitudes (KSA). Building upon this, Le Boterf (1995) defined competence as the capability to deploy KSA resources to tackle complex challenges.

Today, the concept of competence finds application across diverse domains, from professional arenas to educational realms. It signifies a shift from merely possessing knowledge to embodying a multifaceted skill set. This shift underpins competency-based education, a contemporary pedagogical model geared towards cultivating holistic professional capabilities rather than rote content absorption (Lourenço, Nara, Gonçalves, & Canciglieri, 2023; Tardio, Schaefer, Gonçalves, & Nara, 2023; Tardio, Schaefer, Nara, Gonçalves, Dias, Benitez, & Castro e Silva, 2023).

The Pontifical Catholic University of Paraná (PUCPR), situated in Brazil, stands at the forefront of this educational paradigm shift, pioneering the adoption of competency-based models. However, this transition has not been without hurdles. One notable challenge lies in effectively communicating the model's intricacies to students, particularly concerning performance indicators and learning trajectories.

Thus, this study endeavors to address this challenge by implementing visual management strategies within PUCPR's competency-based education framework. Focusing on the Engineering programs, particularly Production Engineering and Control and Automation Engineering, this initiative aims to enhance students' comprehension of the teaching structure and facilitate visualization of their competency progression throughout their academic journey. The choice of Engineering programs is strategic, aligning with the stringent competency standards set by international accreditation bodies like the Accreditation Board for Engineering and Technology (ABET). By enhancing the transparency and accessibility of competency-based education, this research seeks to contribute to the broader adoption and efficacy of this educational model in Brazil (ABET, 2021). In light of this context, the central research question emerges: Can visual management strategies make the competency-based education model more accessible and comprehensible for PUCPR programs? This study seeks to not only answer this question but also to implement and validate practical solutions aimed at empowering students within the competency-based education framework.

# 2 Theoretical Background

## 2.1 Knowledge Management

Knowledge management is the area aimed at managing the knowledge held by an organization, whether it is stored in data or present in employees. This type of management has gained much more strength in recent decades, due to the incredible increase in computational capacity and data availability. Thus, better utilization of this resource can offer significant strategic advantages for organizations (Faria, Tulik, & Gonçalves, 2019).

One way to exercise information management within the organization is through data analysis, as this can provide a greater situational awareness of the context faced. According to Sordi (2015), data is collections of relevant evidence about an observed fact. That is, they are a set of elements about a particular event, and observing a single piece of data is not as effective. Therefore, it is the analysis of the data, the extraction of information from the sets of data obtained from a particular fact. Sinclair (2017) outlines data analysis in a set of three stages: (i) Data preparation: This stage involves identifying and extracting data in its native form, which can be spreadsheets or databases (Vianna, Gonçalves, Dias, & Nara, 2024). They are normalized, a process in which different data is standardized, structured, and processed to be compatible with data analysis. And they are loaded into the database; (ii) Analysis: In this stage, mathematical equations are applied to extract information from the stored data (Junior, & Gonçalves, 2019). (iii) Communicating results: This stage involves using business intelligence tools to express the results and information obtained from data analysis (Gonçalves, Antunes, & Zanellato, 2023).

## 2.2 Visual Management

In today's data-driven landscape, organizations are increasingly recognizing the critical importance of leveraging knowledge assets, harnessing data insights, and fostering transparent communication. The convergence of Knowledge Management (KM), Data Analysis, and Visual Management represents a powerful synergy, enabling organizations to optimize decision-making processes, enhance strategic planning, and drive sustainable growth.

Data Analysis encompasses the systematic exploration, interpretation, and visualization of data to extract actionable insights and inform decision-making processes. Leveraging advanced analytics techniques, organizations can uncover hidden patterns, trends, and correlations within their datasets, enabling them to derive valuable business intelligence and strategic foresight. From descriptive analytics for retrospective analysis to predictive analytics for forecasting future trends, data analysis empowers organizations to make informed decisions and drive performance optimization across various functional domains (Gonçalves, Machado, Nara, Dias, & Vaz, 2023).

Visual Management involves the strategic use of visual aids, such as charts, graphs, dashboards, and infographics, to communicate complex information in a clear, concise, and intuitive manner. By transforming raw data into visually engaging representations, organizations can enhance comprehension, facilitate knowledge sharing, and promote alignment towards common objectives. Through visual storytelling and interactive data visualization, stakeholders can gain deeper insights into organizational performance metrics, project milestones, and strategic initiatives, fostering greater transparency and accountability (Gonçalves, Pamplona, Nara, & Dias, 2023).

In essence, the integration of Knowledge Management, Data Analysis, and Visual Management represents a holistic approach to information management and decision support. By harnessing the collective wisdom of employees, unlocking actionable insights from data, and communicating findings through compelling visualizations, organizations can enhance their capacity to adapt to change, drive innovation, and achieve sustainable competitive advantage in an increasingly complex and dynamic business environment.

# 3 A Visual Management Approach

## 3.1 Solution Planning Process

### 3.1.1 Problem Statement

The Production Engineering program at PUCPR, in accordance with the university's guidelines, has adopted a competency-based education system. In this system, the aim is to empower students to apply their knowledge in real-life situations, defining competence as the set of skills and values that students must acquire throughout their academic training.

To implement this system, it is necessary to map and integrate competencies into the program curriculum in order to guide the planning of activities offered throughout the curriculum.

However, students have faced some difficulty in understanding how the system works, as reported in surveys conducted by ABET with students in the final semester of the program. Specifically, there have been difficulties in understanding how the acquisition of competencies evolves throughout the program, which has not contributed to the development of interdisciplinary projects.

#### *3.1.1.1 Problem Measurement*

Initially, the problem was subjectively estimated through stakeholders' perceptions and observations of the situation, made through direct interactions.

In order to quantitatively measure this perception, indicators were developed to assess stakeholders' and students' satisfaction with the way the competency system is communicated, as well as students' level of understanding of the competency system. These indicators are obtained through surveys conducted with stakeholders.

### 3.1.2 Analysis of Root Cause and Possible Solutions

#### *3.1.2.1 Root Cause Analysis*

The root cause analysis was developed through the use of tools and analysis of data collected with project stakeholders.

Based on the results of the tools used, a hypothesis was raised stating that the main root cause of the problem was related to the lack of a graphical representation that would enable students to see learning in a systemic and evolutionary way. It was termed "main" because it was understood that all other causes would be consequences of the lack of systemic vision. This hypothesis was presented to the Program Nucleus (NDE) in a meeting, where it was accepted and thus became the basis for the development of possible solutions.

##### *3.1.2.2 Possible Solutions*

For the development of solutions, brainstorming tools and a value proposition canvas were used, along with validation with stakeholders to define the best solution proposal.

The chosen proposal would consist of an interactive interface that would change according to each student's performance data. This interface would have its design and functionality based on the skill tree model used in various games. The interface would also be hosted on its own platform, regardless of the online learning platform already adopted by the institution.

After the proposal development period, a meeting was held with the stakeholders, presenting to them the proposals, their justifications, benefits, and gains. It was concluded that the proposal developed in this study was the most appropriate to address the topic.

## 3.2 Implementation of Visual Competency Management

### 3.2.1 Data Collection

The programs of Production Engineering and Control and Automation Engineering at PUCPR are certified by the Accreditation Board for Engineering and Technology (ABET). Because of this, these programs adopt several actions and best practices aimed at their continuous improvement and maintaining accreditation. Many of these actions are related to the establishment and monitoring of performance indicators by the students.

All data from the indicators are stored in databases in spreadsheet format using Excel software. They contain data related to the teaching structure of competencies and the performance indicators of each student. Therefore, the databases provided by the International Accreditation were used to build the graphical interface models.

### 3.2.2 Design Selection

The interface aims to be a visual tool to assist in understanding the competency-based education system. It enables visualizing the individual performance of each student. Therefore, the entire design construction of this tool was based on the structure and flow of teaching present in competency mapping.

The competency-based education system differs from others by structuring its teaching around the competencies learned rather than the courses/disciplines (contents). Competencies are understood as a set of knowledge, skills, and attitudes that need to be mobilized to solve a specific problem. This concept is represented by programs through Learning Outcomes (LOs) and their respective levels. Each LO represents a part of the competency, which can be a small part of the knowledge, skill, or attitude that the competency aims to achieve. Therefore, each competency is formed by a chain of LOs, which over time aims to present and develop each element to the students. This development of LOs over time is expressed through the level system, which consists of three different degrees: introductory, mobilizing, and certifying. In the introductory level, there are learning outcomes that aim to introduce new knowledge to the student; the mobilizing level encompasses LOs that aim to mobilize previously learned knowledge and establish new concepts; finally, the certifying level is where the LOs are aimed at verifying if the student has internalized previous learning. Competencies, as they are not tied to specific content, can have their learning outcomes distributed across different courses/disciplines throughout the program. In addition to the level system, competencies have also been subdivided into competency elements. These divisions aim to separate what is expected of each competency into smaller parts. This entire structure can be observed in Figure 1.

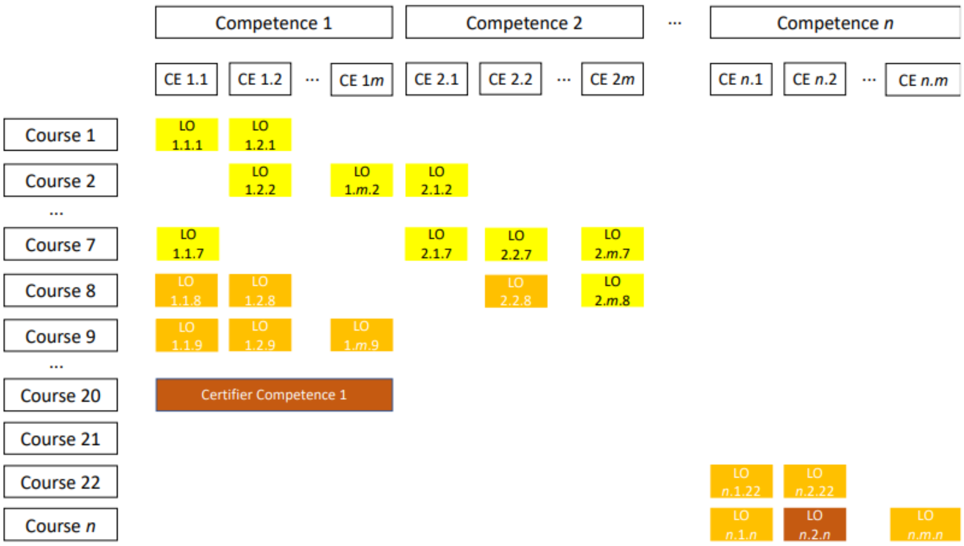


Figure 1. Main screen of the graphical interface.

In Figure 1, we can observe in the columns the competencies of a specific program, where each competency is divided into competency elements, and finally, in the rows, you have the program courses/disciplines (course 1, course 2, ..., course n), where each discipline has different learning outcomes (LOs) that will be evaluated per course. As mentioned earlier, each course may have LOs that contribute to different competencies of the program. The PUCPR system has defined different levels for the LOs, represented by different colours in the figure. The yellow colour signifies an introductory level LO, the orange colour represents a mobilizing level LO, and the brown colour signifies a certifying level LO. With this, it is possible to observe an evolution in the construction of competencies, where each competency has LOs of all levels and concludes with a certifying LO, typically represented per discipline, which verifies if the student has been able to acquire that competency.

For this project, the design was defined in the form of a skill tree, aiming to graphically represent all the structures and mechanisms present in the system as clearly as possible. Therefore, part of the system has its respective graphical representation. Competencies were represented as large tracks, divided into smaller tracks representing competency elements. Each track, in turn, was subdivided into Learning Outcomes, graphically represented in the form of circles. The level system was represented through the colours on the edges of the circles, while the performance of the indicators was represented by the internal colours of each LO. The entire structure was organized in the form of arcs, with the radii of each arc representing the semesters, with the closer to the centre, the smaller the semester.

Next to the skills tree, a panel was developed to insert data related to each Learning Outcome. The proposal is that data such as: Course, grade, code, and the text referring to the Learning Outcome, be displayed when the user clicks on a button corresponding to the LO.

Figure 2 presents the generic interface screen, in which no button is pressed. It is possible to observe three large sections representing the specific competencies of the program. When referring to specific competencies, this includes those directly linked to the professional characteristics of engineering. The other competency pertains to common core competencies, which refer to the basic training of every engineer, a competency that was not of interest in this mapping study. Also, observable are smaller subdivisions representing the elements of competence and buttons representing the learning outcomes (LOs). The same color palette used by PUCPR was employed for its creation.

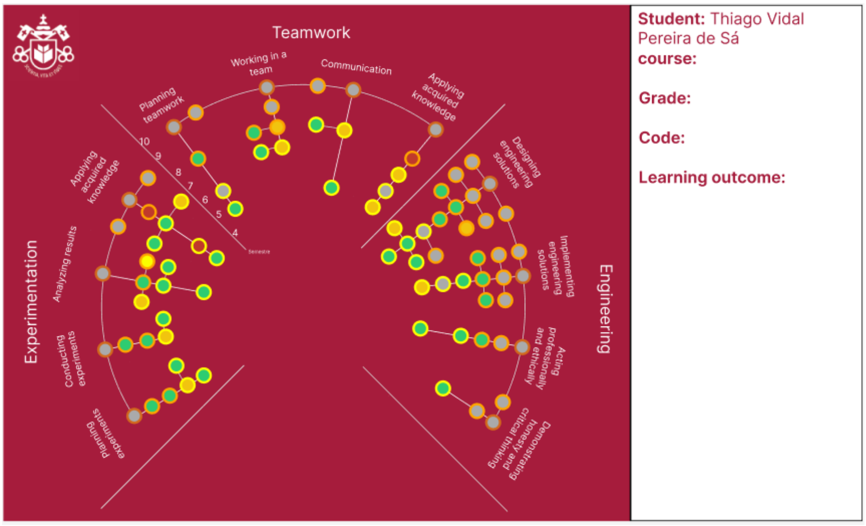


Figure 2. Main screen of the graphical interface.

Figure 2 presents a simulation of the solution for this project, using the student who authored this project as an example. It allows for visual management of the performance of each specific competency in the program. Additionally, different colours indicate the grade obtained in each learning outcome (LO). For example, a grade equal to or greater than 8.5 is shown in green, a grade equal to or less than 7 is shown in red, and grades between 7 and 8.5 are shown in yellow. In the example provided, one can quickly analyse the competencies in which the student excels and those in which improvement is needed. At the time of implementing the solution, the student was in the eighth semester, thus, the performance for the ninth and tenth semesters had not yet been assessed and are represented by the colour grey.

### 3.2.3 Prototyping

The implemented solution was the minimum viable product (MVP) to enable users to understand the proposed design and functionality of the system. For this purpose, the Figma prototyping platform was utilized, a tool commonly used by designers to emulate the basic functionalities of an application before its final construction. With the assistance of this tool, the basic design of the interface was developed along with the button functionalities, which displayed information on the screen when activated.

In the prototyping phase, it was necessary to develop various frames representing the screens after button presses. It was also necessary to create links between the buttons and the respective screens they lead to. This allowed us to emulate the system's functionality, demonstrating the various possible screen flows in the system's operation.

## 3.3 Validation of the Implemented Solution

In order to assess the acceptance of the solution by the users and identify possible improvements, evaluative forms and interviews were developed for the two audiences who would benefit from the new tool, the professors and the students. Each audience has different needs to be addressed. The students represent the main audience, aiming to offer them assistance in understanding the functioning of the competency-based education system and a graphical tool for monitoring their performance according to the competencies. For the professors, the aim is to provide an evaluative tool that can diagnose the students' performance according to the competency-based education model and not just by courses.

### 3.3.1 Measurement of Improvement Using Success Indicator

With the students, quantitative evaluations were also conducted in which ratings from 1 to 5 were assigned to the following topics: Understandability, usability, design, intuitiveness, and usefulness. In addition, inquiries were made about the prior knowledge each one had regarding the functioning of the competency-based education model and how much this knowledge improved after the presentation of the tool. Out of the 23 respondents, 13 answered the objective questionnaire. The following table presents the evaluated items and their respective average ratings:

Table 1. Average scores of evaluative criteria.

| Question | Average grade |
|---|---|
| How well could you understand the functioning of the competency system before the presentation with graphical representation? | 2,5 |
| How much did your knowledge about the education system improve after the presentation? | 4,7 |
| How do you assess the intelligibility of the interface? (It's how understandable the system is to the user) | 4,3 |
| How do you assess the usability of the interface? (It's how easy it is for the user to use the system to extract information) | 4,6 |
| How do you assess the design of the interface? (Refers to the organization of information, color palette, and responsiveness of the system.) | 4,3 |
| How do you assess the intuitiveness of the interface? (It's how understandable the system is to the user without needing secondary information) | 3,9 |
| How do you assess the usefulness of the interface? (It's how useful the system can be for users, beyond its primary function) | 4,8 |

Before the solution was presented to the students, it was observed that the average obtained was below 2.5 for the questions on the form, and after implementing the solution, according to table 1, the majority of questions obtained average values above 4. This indicates that the use of a graphical tool had a significant impact on users' perception.

# 4 Final Considerations

Therefore, it can be observed that the application of graphical tools to the context of competency-based education model aids in improving its intelligibility. In this work, methodologies and tools were used to meet the general objective and the specific objectives. The aim was to find and identify problems and their causes through the use of tools related to the scope of agile methodologies, such as brainstorming and the value proposition canvas. To implement the solution, the Figma platform was used to build the graphical interface design. Finally, to understand the stakeholders' opinions regarding the proposed solution that was implemented, interviews and quantitative research were conducted. Therefore, it can be concluded that the project achieved its desired objective.

To scientifically validate the proposed model, a comprehensive literature review was conducted. This review revealed that there are no previous studies directly addressing this specific model in the context of competency-based engineering education. This absence of studies highlights the originality and innovation of our proposal (Gonçalves, Nara, Santos, Mateus & Amaral, 2023; Hamasaki, Gonçalves, Junior, Nara, & Wollmann, 2023; Lourenço, Gonçalves, Canciglieri Júnior, Dias, Benitez, Benitez, & Nara, 2024; Serra, Nara, Gonçalves, da Costa & Bortoluzzi, S.C., 2023; Serra, Gonçalves, Bortoluzzi, Costa, Dias, Benitez, Benitez & Nara, 2024; ). Throughout the project development, several constraints and limitations were encountered. A strict delivery deadline and limited availability of resources were among the constraints. These factors posed limitations on the project's freedom of action. Therefore, it was necessary to confine the project to a level of simplicity, always aiming to find the minimum viable solution to address the issue at hand.

It is suggested, as a proposal for future studies, to expand the application of the visual management tool to the job market area, targeting companies that use the competence-based model to select their candidates. The aim is to use the tool as a basis to produce a new interactive competency-based resume model. This will facilitate communication between candidates and companies, making it easier to identify the candidate's professional profile.

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# Educational Strategies for Sustainable Futures: Revealing the Priorities and Perspectives of Engineering Students

Luiz Ney d'Escoffier[1], Aida Guerra[2], Marcia Terezinha Longen Zindel[3]

[1] Laboratório de Protozoologia, Instituto Oswaldo Cruz, Fiocruz, Brasil
[2] Aalborg Center for Problem-based Learning in Engineering Science and Sustainability, Aalborg University, Aalborg, Denmark
[3] Faculdade de Tecnologia, Departamento de Engenharia de Produção, Universidade de Brasília, Brasil

Email : lescof@gmail.com; ag@plan.aau.dk; marcialz@unb.br

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**Abstract**

In 2015, the UN adopted the 17 Sustainable Development Goals (SDGs) as part of the "Agenda 2030". These are interconnected goals that address the main development challenges facing the world. Engineers play an important role in the achievement of the UN's SDGs by developing innovative and sustainable solutions. Therefore, the knowledge, skills, and competencies engineers are equipped with upon graduation are fundamental to be able to actively participate and perform in tackling present and future sustainable problems. Existing studies report the development of self-perceived skills by students after a pedagogical intervention; however, they do not examine why certain skills are prioritized over others. Additionally, most research approaches are quantitative and do not deepen the understanding of why students position themselves concerning sustainability competencies. This study reports on students' perspectives and needs regarding their competence's development for sustainability by examining what they consider as the most important skills to act for sustainability and why. It takes a qualitative approach, where open-ended questions were thematically analyzed. The study involved 18 students from an international master's program in Sustainable Design at Aalborg University, Denmark, and 26 students from the Production Engineering course at the University of Brasília, Brazil. Our results demonstrate a multidimensional vision, prioritizing collaboration, interdisciplinarity, and systemic and problem-oriented thinking. They see the importance of education for sustainability as a motivator for future generations, in addition to the need to know how to look at reality to identify problems and seek a fair and sustainable society. These results point to a holistic and conscious view of students concerning sustainability, and these conclusions can guide educational strategies and initiatives that aim to develop these skills and values among students.

**Keywords:** Sustainability Education; Competencies Development; Engineering Education.

# 1 Introduction

Sustainable development seeks to meet the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland et al., 1987), taking into account the balance between the environment, economy, and society (Elkington, 1994). Thus, it is fundamental for an effective transition towards a more ecologically balanced society and economy (EU Science Hub, 2022). In 2015, the UN adopted the 17 Sustainable Development Goals (SDGs) as part of the "Agenda 2030" (UN, 2015). These goals aim to solve global challenges such as poverty, environmental degradation, and climate change and promote peace and prosperity. For these goals to be achieved, a transformative and ecological approach to learning is advocated to enable students to promote sustainability (Boström et al., 2018; Hermes & Rimanoczy, 2018; Sipos et al., 2008).

Competences for Sustainable Development (SD) are now a requirement for individuals and organizations must adopt practices to achieve the UN Sustainable Development Goals (SDGs). According to Wiek (2011), these competences go beyond thematic knowledge and encompass a combination of knowledge, skills, and attitudes to face real sustainability challenges. A distinction has been suggested between basic skills, which address general learning objectives, and key skills for sustainability, which are more specific and detailed (Wiek et al., 2011; Wiek et al., 2015). Wiek (2011) highlights six key competences for sustainability, such as systemic thinking, anticipatory, normative, strategic thinking, collaboration, and integrated problem solving, which are recognized by UNESCO (2017) as crucial to achieving the SDGs.

Engineers play a key role in promoting a sustainable future through innovation. However, dealing with complex challenges requires specific competences. Studies on the competences necessary for Engineering Education for Sustainable Development (EESD) highlight the importance of problem-solving (Thürer, 2018), interdisciplinary and transdisciplinary skills (Guerra, 2017), strategic skills (Quelhas, 2019), intradisciplinary skills and interpersonal (Ortiz-Marcos, 2020) for educators and engineering professionals. However, there is little research into the competences developed by engineering students in the EESD.

Recent studies on sustainability competences include systematic literature reviews (Annelin & Boström, 2023; Redman & Wiek, 2021) and reports examining the development of students' self-perceived competencies following pedagogical interventions, predominantly using quantitative research methods (Cebrián, Pascual & Moradela, 2019; Cavicchi, 2021; Balakrishnan et al., 2020), which mainly employ Likert-scale self-assessment questionnaires. However, the lack of qualitative approaches makes it difficult to understand student preferences, namely what they consider important and why. Furthermore, the lack of clear criteria for why students choose certain competencies in the questionnaires makes it difficult to correlate them with the key competences for sustainability described by UNESCO (2017).

This study, which is part of a broader research project, aims to explore students' perspectives on the competences needed to act for sustainability and reports on student justifications of why they consider certain competences more important than others.

# 2 Methodology

## 2.1 Research context and participants

The study was carried out at the Department of Production Engineering of the Faculty of Technology of the University of Brasília (hereinafter UnB), Brazil, where 26 students from the undergraduate course in Production Engineering participated voluntarily, and at the Department of Sustainability and Planning, Aalborg University (hereinafter AAU), Denmark, where 18 students from an international master's program in Sustainable Design participated in the same way. The research context of the institutions is described in Table 1.

Table 1. Research context of the two educational institutions where the work was carried out.

| University of Brasília | Aalborg University |
|---|---|
| The production engineering course at UnB spans 12 semesters, designed to equip engineers with a systemic approach to tackling engineering challenges. Emphasizing the interaction between professionals and their environments, sustainable development is a key focus. Starting from the 4th semester, students engage in the "Production System Projects" (PSP) course, employing Problem-Based Learning (PBL). Projects undertaken in PSP are offered to external companies pro bono, targeting solutions for customer-raised issues, particularly in sustainable service production systems. Faculty members from UnB's Faculty of Technology guide these projects within the Production Engineering Department. | Since 1974, Aalborg University (AAU) has employed a problem-based, project-organized learning (PBL) model. This approach involves students tackling real-world problems in small groups, with each semester structured around three courses (5 ECTS each) and one problem-based project module (15 ECTS). This method fosters the development of knowledge, competencies, and transversal skills such as problem design, communication, project management, teamwork, and critical thinking. AAU prioritizes the United Nations' Sustainable Development Goals (SDGs), integrating them into its strategic focus. The MSc in Sustainable Design at AAU is a comprehensive engineering program where sustainability is a fundamental value, not an add-on. The program places a strong emphasis on facilitating transitions to sustainability through radical systemic changes. |

## 2.2 Research design

As part of the broader study, participants from UnB and AAU were asked to rank from most important to least important a set of sentences that refer to sustainability competences. The study used Q methodology as the research design (learn more about Q methodology at: https://qmethod.org/), and which results will be reported in two journal articles. Nonetheless, the broader study also comprised open questions, where students are inquired about why they consider certain competences more relevant than others, as well as what type of competences could be further integrated into their educations. Open questions from 39 students were subjected to manual thematic analysis of the data (18 from AAU and 26 from UnB), taking an inductive approach.

The choices were categorized according to the corresponding competence. The justifications were analyzed to understand the reason why that statement was chosen, verifying the consistency of the competence related to the statement. They were then used to draw a qualitative profile of the classes regarding their perspectives on the role of engineers in sustainable development.

# 3 Results

In both institutions, system thinking, collaboration, and systemic thinking are considered the most important competences; whilst knowledge about SDGs and perceived as least important. The following sub-sections provide an overview of why students consider these three competences more or less important to act for sustainability.

## 3.1 Engineering complex problem solving and the need for systemic view to understand them

The perception of the engineer's need to have a systemic view of problems and possible solutions is strongly present in students of both courses, as we can see below from the justifications given (for better understanding, the justifications are preceded by a code defined by a letter, where "A" represents AAU students and "B" represents UnB students, followed by a student identification number):

B-7 "*Having a holistic view is essential to develop sustainable solutions that address not only the environmental but the general scope*";

A-8 "*As an engineer, I believe our job is more about analyzing and identifying complex problems, and what are the reasons for unsustainable practices to then take these findings and collaborate with other experts and people that can force change*";

A-14 "*I think that is the base of everything in my profession. It should be almost a way of thinking and working that we have by default without this I don't think other ones make a lot of sense. It should be our culture as sustainable design engineers*";

B-21 *"It is essential to understand the impacts that a project can cause, understanding the economic, social and environmental nature of the decisions that define whether it is executable or not";*

B-30"*A holistic view of the system is essential for identifying the elements of a system as well as its advantages, disadvantages, and bottlenecks*".

Although some statements were not chosen in large numbers, their justifications gain significance when analyzed together. The problem-solving-oriented vision takes on an interesting dimension when we examine the students' claims:

B-17 "*With the notion of the importance of the system's structures, it becomes easier to distinguish what is relevant to the problem to be solved, and whether it is feasible to proceed with the implementation*";

A-22 "*Being able to create design strategies for sustainability is the premiss for all others design work that comes after & it is relevant throughout the whole project process as things change*";

B-26 "*Strategy is one of the most important pillars for solving problems and projects*";

## 3.2 Collaboration with the people involved provides a deep and authentic understanding of reality.

Collaboration was also strongly present, by recognizing that they need the collaboration of stakeholders to understand their reality and better contextualize the problem. According to them, this recognition of reality is important to facilitate the search for a more efficient solution to the problem, as follows:

A-2 "*Firstly it's necessary to understand the current situation to see a problem's context and work towards solving it - which requires collaboration with actors in this context as they are the ones who have to realize a solution*";

A-26 "*I find working with multiple teams most important, as I think it is important to include different perspectives when solving sustainability problems - I think this strengthens the solution*".

Collaboration can again be interpreted as interdisciplinarity, as analyzed in the statement below:

B-16 "*Working with experts from various disciplines brings different possibilities, creative ideas, and a much better-expected result*";

## 3.3 Interdisciplinary as 'transversal' and connected competence

Although interdisciplinarity is not determined as a key competence for sustainability (Wiek, 2011), students understood its importance. In their speeches justifying the choice of the most important statements, interdisciplinarity appears integrated with systemic thinking and collaboration skills.

We can notice that, even though students chose statements related to systemic thinking, their justifications point to a view related to interdisciplinarity, as in the following statements:

B-3 "*Complex problems in various disciplines involve deconstructing a large problem into smaller problems, thus enabling them to be solved by different specialists*";

A-4 "*I think that this is our superpower as SDE! To understand complex problems through multiple lenses/disciplines. I think that real sustainable solutions call for multiple disciplines, and I think it is very unique for our disciplines that we can manage this*";

A-21 *"We as humans will never have all the knowledge in our heads as multiple specialists on their jobs. We need to listen to them and gather the all-important data to facilitate sustainability"*.

Similarly, collaboration can be interpreted as interdisciplinarity, as analyzed in the statement below:

B-16 "*Working with experts from various disciplines brings different possibilities, creative ideas, and a much better-expected result*";

## 3.4 Criticisms towards SDGs, radicalism, and lack of flexibility as important reflections when it comes to acting for sustainability

When asked about the least important competences, students refuted the idea of associating projects with the UN SDGs. According to them, the SDGs are general objectives and do not consider the particularities of each region, and their use as a reference can hide important local problems, as in the following comments:

A-3 "*The SDG is very vague. New opportunities could be explored by people/stakeholders on their own since they have an intrinsic desire to push forward the sustainable agenda";*

A-13 *"Because it is incredibly prescriptive, scenarios are excellent tools but are building on limited scenarios, limited views of the world*";

A-23 *"To solve the issues at hand we would need to look at the local problems and environments. That can be very difficult when working with SDGs as many of these are global or at the very least international. It is a problem because it is difficult to fix the world if you don't even know how to fix your country or region first"*.

On the other hand, the word "radical" in one of the statements was interpreted in two ways: radicalism as a violation of democratic values (B-14 "*When you expose your radical personal positions, there is a great risk of generating discord among the group*") or as inflexibility (B-12 "*It is important to have flexibility in the face of challenges and agents*").

Both positions, whether a criticism of the SDGs or a concern with radicalism, regardless of the interpretation, demonstrate an awareness and consideration for contextual elements that determine the problems but also the sustainability of solutions. This means that one solution does not fit all and that even though sustainability challenges are global, collaborations, problems, and solutions need to be addressed with local knowledge and capabilities.

# 4 Discussion and conclusion

According to the results presented, we realized that students' perceptions regarding the sustainability competences necessary for engineers to solve complex problems related to sustainability are aligned with the definitions of sustainability and the standard of education for sustainability, which are systemic thinking, interdisciplinarity and collaboration (Guerra & Holgaard, 2019; Guerra & Smink, 2019; Sterling, 1996, 2001). These findings suggest that students recognize the need to understand complex and interconnected systems that sustain socio-environmental challenges, in addition to valuing the need to use different experts from different areas to address the problem more comprehensively and effectively.

The justifications also show that interdisciplinarity is perceived as transversal and plays a role in connection with different competences. For example, students stress it as relevant in collaborative processes, whilst in others they connect to systems thinking and complexity.

Taking into account that all key competences for sustainability are equally important and that people, especially, in our case, engineers, need to develop them together, our findings can guide the development of educational strategies to develop these competences and values among students. On the other hand, the convergence in views of students from universities in different countries can be attributed to a combination of factors, including the globalization of knowledge, similarities in engineering curricula, academic and environmental culture, global environmental sensitivity, and similarities in sustainability challenges faced around the world. In this way, a joint, global effort to plan efficient means for developing key competences for sustainability is valid.

In conclusion, the results obtained highlight a multidimensional approach, where systemic thinking, collaboration, interdisciplinarity, and problem-solving are highly recognized and prioritized to be part of engineering education for sustainability action. They recognize the importance of education for sustainability as a boost for future generations, along with the ability to analyze reality and identify challenges, aiming for an equitable and sustainable society. These findings reflect students' holistic and conscious understanding of sustainability, offering valuable guidelines for educational strategies and initiatives aimed at developing these skills and values among students. In this context, the incorporation of sustainability themes into existing disciplines and the use of active methodologies, such as Problem/Project Based Learning (PBL), can be useful not only develop students' theoretical understanding of sustainability but also encourage the application practice and development of values and sustainable behaviors that will last throughout their lives.

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# Implementation of a Smart Manufacturing Systems Laboratory for Manufacturing Planning and Control

Ivo Teixeira[1], Paulo Martins[1], Rui M. Sousa[1], Guilherme Pereira[1]

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

Email: pg42919@uminho.pt, pmartins@dps.uminho.pt, rms@dps.uminho.pt, gui@dps.uminho.pt

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**Abstract**

Industry 4.0 is reshaping Manufacturing Planning and Control (MPC) processes in order to implement flexible and integrated manufacturing systems capable of dealing with high levels of product diversity and customisation. Smart Factories are one of the greatest products of Industry 4.0, in which all manufacturing system activities are managed and scheduled by Information Technology support systems, in real-time, according to the context where they are inserted, also referred to as Smart Manufacturing Systems (SMS). The objective of this paper is to describe the implementation of a SMS laboratory that reproduces the manufacturing environment of a Smart Factory, as well as a pilot-test of that same facility. The SMS Laboratory was designed and implemented by the academic staff from the MPC area from University of Minho (Portugal), to be used in different course units of Industrial Engineering and Management (IEM) programs. The purpose is to create an active learning experience, involving hands-on activities/learning-by-doing, where students are the operators and can witness/understand how a Smart Factory should work. The SMS Laboratory consists of 7 workstations, 4 warehouses, 3 transport systems and 1 maintenance workstation, and all activities are managed by a proprietary software (SMS). During the experience, students choose the quantity and type of goods to manufacture, among 2 types of products, a dummy product with 2 variants and a flashlight with 4 variants. The operation of the facility was first tested by the authors and then a pilot-test was carried out with a group of 9 people. The test was successful and allowed to collect valuable feedback to improve the experience, to make it more dynamic and keep students' attention. Soon, the SMS Laboratory will be used by two-course units of IEM programs and the application in other areas is also being analysed, namely Production Organization, Quality Control and Maintenance Management.

**Keywords**: Industry 4.0; Engineering Education; Active Learning; Smart Manufacturing Systems; Smart Laboratory.

## 1 Introduction

Over the last centuries, the industry sector has gone through major changes to deal with technological, business, and organizational challenges. Nowadays it is globally accepted that industrial organizations are witnessing the fourth industrial revolution, also referred to as Industry 4.0. Traditional manufacturing systems relied mostly on human labour and equipment, limiting their efficiency and flexibility. The emergence of new technologies across several areas, such as automation, robotics, data analysis and information systems, marked the beginning of the fourth industrial revolution (Xu et al., 2018) – which aims to address the limitations of traditional manufacturing systems by implementing digital, smart and integrated systems (Zhou et al., 2015).

Industry 4.0 aims at a stage of full integration and synchronization between all entities of manufacturing systems, including humans, equipment, devices, and systems involved in all manufacturing processes (production, transportation, warehousing, quality control, etc.). This manufacturing environment is commonly referred to as Smart Factories, where activities are defined and supported by Information Technology (IT) support systems, in real-time, according to the context where they are inserted. IT support systems that support the management and control of manufacturing system activities are also referred to as Smart Manufacturing Systems (SMS) (Kagermann et al., 2013; Lucke et al., 2008; Zheng et al., 2018).

In Industrial Engineering and Management (IEM) programs, the development of competences for Industry 4.0, Smart Factories and SMS is a matter of utmost importance, especially because Industry 4.0 is reshaping

Manufacturing Planning and Control (MPC) processes and because more and more companies need to apply these competences to become more efficient and competitive in the market.

Active learning approaches are becoming increasingly popular in engineering education because they improve student's learning ability, both in terms of technical and transversal/soft competences (Christie & Graaff, 2016; Guo et al., 2020; Lima et al., 2007; Sousa et al., 2023). The application of these approaches to the development of the competences mentioned above plays an even more crucial role because a large part of the program contents refers to a set of abstract concepts and functions that are not easily understood (since they do not exist in physical space). Therefore, when it is possible to create laboratory facilities in which students can apply these competences or witness the result of their application (involving hands-on activities/learning-by-doing), the achievement of the expected learning outcomes is more robust and faster.

This paper aims to describe (i) the implementation of a laboratory that reproduces the manufacturing environment of a Smart Factory (designated as SMS Laboratory), and (ii) a pilot-test carried out in that facility. The SMS laboratory is located in the Department of Production System (DPS) at the University of Minho, Portugal, and was designed by a group of teachers and researchers in the MPC area. The SMS Lab aims to provide an active learning experience, involving hands-on activities/learning by doing, where students from different IEM programmes play the role of operators and experience/understand how a Smart Factory works.

The paper is structured in five sections. Section 2 presents the methods used to carry out this work. Section 3 describes the implementation of the SMS Laboratory and the pilot-test of the facility. Section 4 discusses the main applications and results of the laboratory. Section 5 presents the final remarks of the paper.

# 2 Methods

The implementation of the SMS Laboratory was led by the authors of this paper and consisted of three stages: (i) physical implementation of the facility, (ii) informatic representation of the information needed to manage MPC processes and (iii) creation of a set of tests to validate the operation of the SMS Laboratory.

A manufacturing system consists of a set of humans, equipment and systems used throughout the manufacturing process of a product (Kosacka-Olejnik et al., 2021). To implement a manufacturing system in the facility, in the first stage, it was identified and collected some of the equipment available in the DPS, namely workstations, storage structures, material transport equipment, products to be manufactured/assembled, tables, chairs, among others. Then, the authors defined the layout of the facility and set up the SMS Laboratory. Each physical element of the manufacturing system has been labelled (visual management) to streamline the transport and storage processes. Besides that, the technological infrastructure to support the application of the software was also installed (server, terminals, network, etc.).

In the second stage all physical elements of the manufacturing system were represented in a proprietary SMS software recently developed at DPS, also referred to as "digital twin" of the manufacturing system, to "provide a mirror of physical shop floor" reflecting the "real-life" status of each object (Wang et al., 2019).

Finally, the operation of the SMS Laboratory was first tested by the authors and then a pilot-test was carried out with a group of nine people of the MPC area from the DPS (professors and researchers) to validate if the main purpose of this work were achieved: make easier to understand how a Smart Factory should work and facilitate the development of competences in this area.

# 3 The Smart Laboratory

This section is divided into four subsections. The first subsection shows the set of products and operations that can be executed in the SMS Laboratory. The second subsection describes the workstations and layout of the facility. The third subsection describes the information represented in the SMS software to manage all activities of the facility. The last subsection describes the tests that have been carried out so far.

## 3.1 Products, Items and Operations

The SMS Laboratory is prepared to manufacture six different products (Figure 1): two dummy products assembled with plastic and metallic pieces, and four flashlights with different colours. It should be noted that these are just some examples – other products can be implemented to be manufactured in the SMS laboratory.

Dummy Product A (Black Handle – Black Base) | Dummy Product B (Yellow Handle – Green Base) | Red Flashlight | Blue Flashlight | Yellow Flashlight | Black Flashlight

Figure 1. Pictures of the products manufactured in the SMS Laboratory

Each product has a set of properties defining information to MPC processes, a Bill of Materials (BOM), and a routing. The BOM and routing are the list of components/parts and the sequence of operations to manufacture a product, respectively. Figure 2 depicts the BOM and routing of Dummy Product A and Red Flashlight.

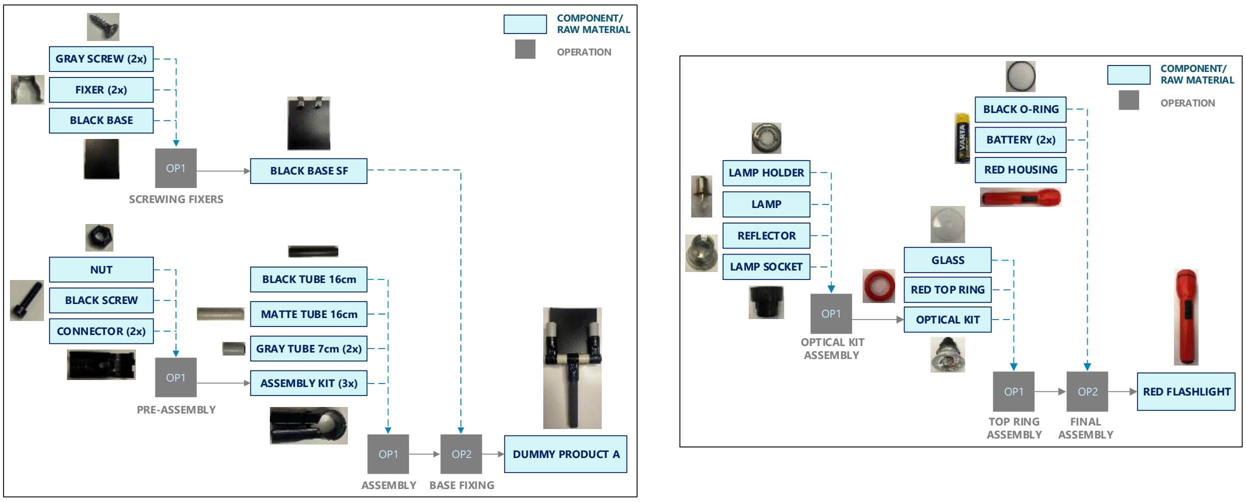



Figure 2. Bill of material and routing of Dummy Product A (Black Handle – Black Base) and Red Flashlight

The manufacturing process of Dummy Product A consists of two operations: assembly and base fixing. The first requires four tubes and three units of the assembly kit (semi-finished product). The second operation can only be executed after the first and requires the black base semi-finished. Each semi-finished product needs a single operation and a set of components. The manufacturing process of the Red Flashlight starts with the assembly of the optical kit that requires the following components/raw materials: lamp holder, lamp, reflector and lamp socket. Next, the red top ring and the glass are added to the optical kit (assembly – flashlight top). The manufacturing process of the Red Flashlight ends with the joining of the flashlight top (work-in-process that results from the previous operation), the red housing, two batteries and a black O-ring. The BOM and routing of the Dummy Product B and remaining flashlight are also similar but some of the items required are different.

## 3.2 Manufacturing System

The manufacturing system implemented in the SMS laboratory consists of seven workstations, four warehouses/supermarkets, three milk runs (transport systems), two suppliers and a maintenance workstation. Figure 3 provides an overview of the SMS Laboratory. Table 1 contains a picture of each element.

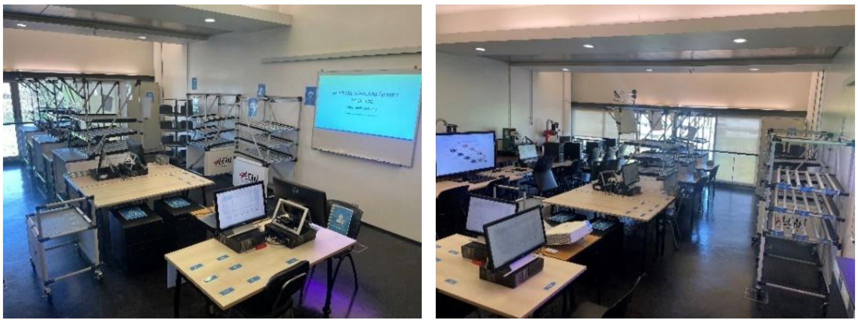


Figure 3. Overview of the SMS Laboratory

Table 1. Workstations, warehouses/supermarkets and milk runs of the SMS Laboratory

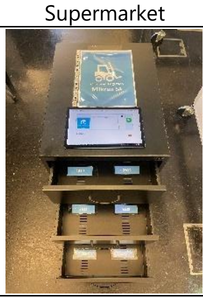
| | | | | |
|---|---|---|---|---|
| **Workstations** |  |  |  |  |
| | Workstation 1 | Workstation 2 | Workstation 3 | Workstation 4 |
| |  |  |  |  |
| | Workstation 5 | Workstation 6 | Workstation 7 | Maintenance Workstation |
| **Warehouses/ Supermarkets** |  |  |  |  |
| | Raw Materials Warehouse 1 - Metal | Raw Materials Warehouse 2 - Plastic | Semi-Finished Supermarket | Final Goods Warehouse |
| **Milk Runs** |  |  |  | |
| | Inbound Milk Run | Raw Materials Milk Run | Semi-Finished Milk Run | |

Table 2 defines the set of operations each workstation can execute (referred to as workstation skills), considering the routing of each product (Figure 2). Workstations 4 and 7 execute repackaging and packaging operations (not considered in the examples presented).

Table 2. Skills of each Workstation

| Workstation | Product Type | Operation |
|---|---|---|
| Workstation 1 | Dummy Products A/B | Pre-Assembly |
| | Flashlights | Assembly – Optical Kit |
| Workstation 2 | Dummy Products A/B | Pre-Assembly |
| | Flashlights | Assembly – Optical Kit |
| Workstation 3 | Dummy Products A/B | Assembly |
| | Flashlights | Assembly – Flashlight Top |
| Workstation 5 | Dummy Products A/B | Screwing Fixers |
| Workstation 6 | Dummy Products A/B | Base Fixing |
| | Flashlights | Final Assembly |

The warehouses/supermarkets are storage structures where materials should be placed and stored. The metallic raw materials are stored at 'Raw Materials Warehouse 1 – Metal'. The plastic raw materials are stored at 'Raw Materials Warehouse 2 – Plastic'. All semi-finished products are placed at 'Semi-Finished Supermarket' and all final products are placed at 'Final Goods Warehouse'.

The milk runs are responsible for transporting most of the materials over the facility, between workstations and warehouses/supermarkets. Figure 4 illustrates all milk run routes, that is, the sequence of points visited by each milk run. Each milk run route is illustrated with a different colour.

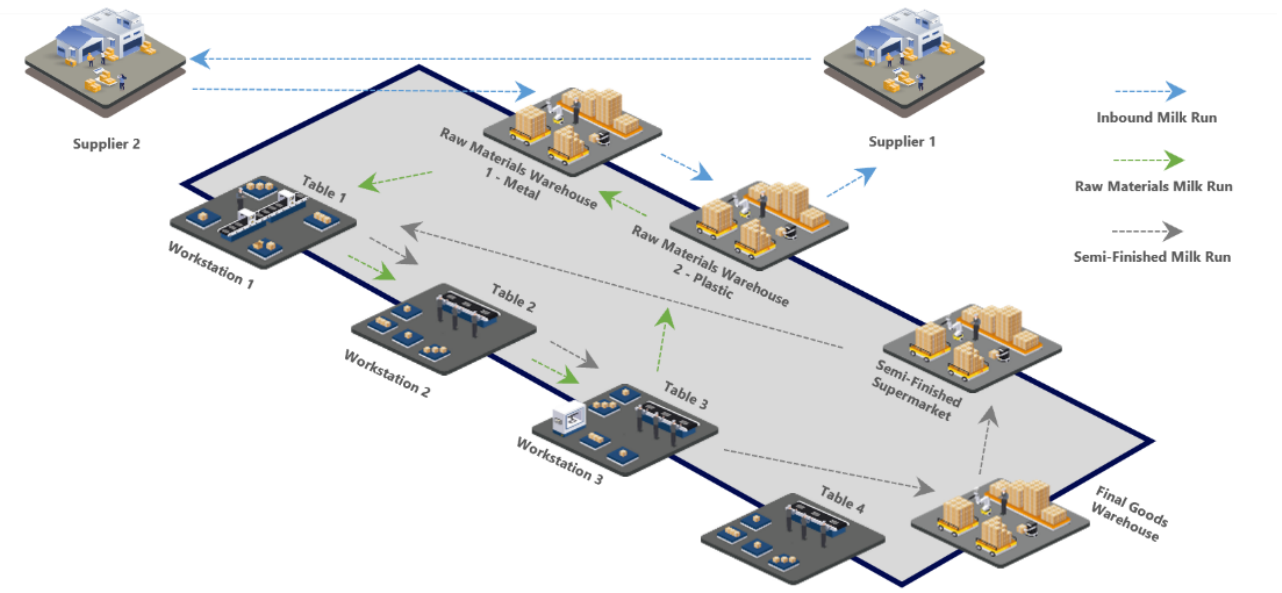



Figure 4. Scheme of milk run routes

## 3.3 Smart Manufacturing System

The SMS software that controls the activities executed in the SMS Laboratory is an integrated MPC system that covers four main functional areas, illustrated in Figure 5. Product Data Management refers to the functional area where all information about the products is defined and managed. The Organization Data Management is the area where all information about the entities that influence a manufacturing system is defined, including workstations, warehouses, supermarkets, transport systems, or even external entities (customers and suppliers). Production Planning and Control (PPC) (also referred to as medium-term planning) includes a set of functions that results in a plan about what must be produced, bought, or outsourced, in which quantities, in which dates and the number of resources needed to meet the plan. Lastly, the Shop-Floor Control (SFC) functional area (also called short-term planning) includes a set of functions to schedule and automatically sequence (without human intervention) all jobs and activities, to all entities that influence the manufacturing system.

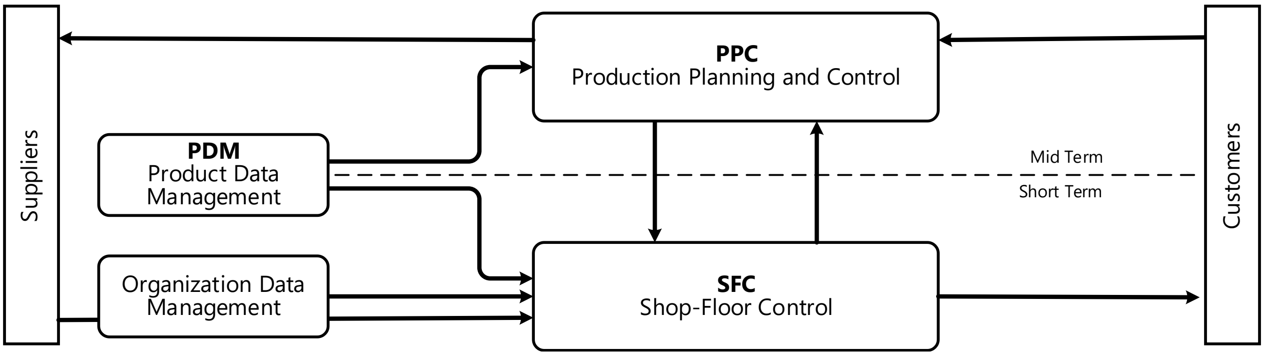
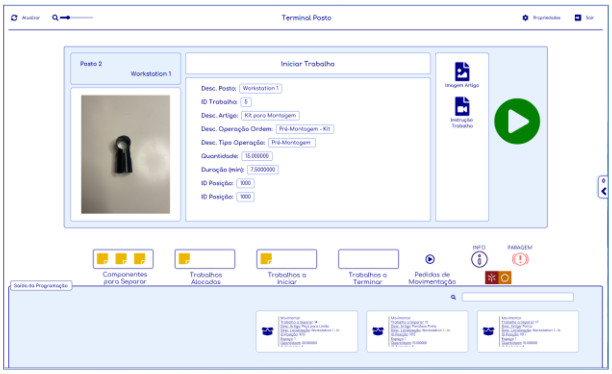



Figure 5. Smart Manufacturing System – Software Architecture

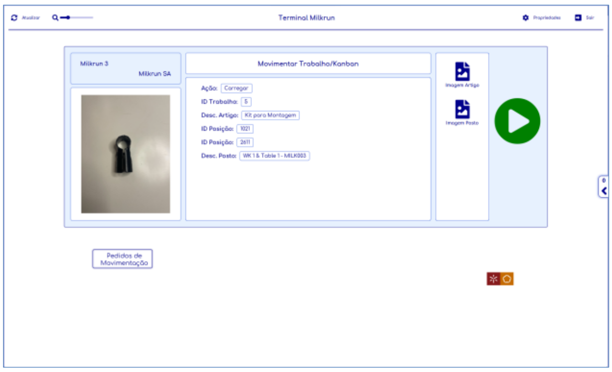
The set of PPC and SFC functions implemented in the software is able to automatically manage all planning and scheduling activities in the manufacturing system (in order to implement a Smart Factory), but these functions require information of all entities and products in the manufacturing system, including information about different products, types of entities, their behaviours, properties, organization, rules and restrictions to which they are subject. Most of the information refers to the information described, in a simplified way, in the previous sections, which has been represented by the authors in the software. Some support documents (videos, images, and PDF files) of how to execute each operation were also defined in the system, to ensure that users without experience or training could execute any operation.

The SMS software interfaces to interact with final users were also defined by the authors, including those to key users (managers, planners, etc.) and work users (workers at each workstation or milk run). Figure 6 shows some examples of those interfaces. Figure 6(a) displays the number of jobs (also referred to as kanban) assigned to each workstation. Figure 6(b) shows an example of a workstation interface – in this example, the interface is suggesting starting the 'Pre-Assembly' operation of an 'Assembly Kit' at 'Workstation 1'. Figure 6(c) shows an example of a milk run interface – in this example, the interface is suggesting to the 'Semi-Finished Milk Run' to load a set of 'Assembly Kits' at position '1021' of 'Workstation 1' and place it at position '2611' of the milk run.

(a)



(b)



(c)

Figure 6. Examples of interfaces of the SMS software (a) general manager, (b) workstation, (c) milk-run

## 3.4 Usability and Functional Tests

The initial functional tests of the SMS Laboratory were performed by the authors to make sure the information was properly defined in the SMS software and that the facility was properly designed. Then, a pilot-test was carried out with a group of nine people of the MPC area (teachers and researchers), aiming to collect informal feedback and a critical view from people with experience and competences in the MPC area, before testing the SMS Laboratory learning experience with students. The main goal of the pilot-test was to validate if a set of products (among the products presented in Figure 1), chosen by the group at the beginning of the experience, could be manufactured in the SMS Laboratory without human interference in the planning and control of activities. The group decided to manufacture three units of red flashlights. No training was given to workers to perform the required activities. The SMS software identified and assigned all activities that needed to be executed and provided all required information for workers to execute each activity, including work instructions (videos, PDF files, etc.) or information about the positions where each object should be placed. Figure 7 shows some pictures of the pilot-test.

Figure 7. Pictures of the pilot-test

At the end of the pilot test, in a brainstorming session, workers' feedback was collected informally and recorded. Additionally, the authors made notes on their own perception of the experience.

# 4 Discussion

The pilot test showed that the SMS software ensured total control of the system, from the triggering of purchase orders to suppliers of components/raw materials, to dispatch to the end customer, passing through to the allocation of operations to workstations and milk runs responsible for all internal transport between warehouses/supermarkets and workstations (also managing the exact positions within each of them). From this perspective, the feedback gathered was clearly positive; the pilot test was successful as it ensured the production of the set of flashlights stipulated (without human intervention in the planning and control functions) and the group understood the importance and the comprehensiveness of the work developed. However, some problems were identified, particularly in relation to the start-up of the pilot test and the SMS software interfaces. The initial steps of the pilot test were boring for the workers who had to wait until they had raw materials/components to start working. This was because the pilot test started with the system unloaded (empty) and was further aggravated by the fact that there was only one worker assigned to the milk run. Furthermore, during the manufacturing process of the red flashlights, the authors had to provide some support at each workstation, mainly to help workers interpret the information displayed in each software interface. In fact, it was identified that in the SMS software, the workstation and milk run interfaces were giving equal emphasis to the activities to be carried out by the respective workers, as to other secondary information (e.g. workstation description). This meant that workers' perception of what they had to do (what operations and in what quantity) was not as quick as it should be.

To overcome these issues, some approaches to improve the experience (to be carried out later with the students) are being discussed and implemented, such as (i) reducing the information provided on each interface of the SMS software and emphasising the most important (to make it easier for each worker to interpret), (ii) ensuring that all workers do not have to wait at the start of the experience by increasing the number of milk runs to three and assigning additional operations to their workstations (loaded system) and (iii) defining a better strategy for introducing the learning experience (to better contextualise the students about what will happen). In the next semester, the learning experience at the SMS Laboratory will be carried out in two curricular units: Information Systems for Production, and Information Systems for Production Management, from the two IEM programs of the DPS at the University of Minho (master’s in industrial management and engineering and master's in engineering and operations management, respectively). Application to other curricular units in the IEM area is also being analysed, as the SMS Laboratory can also be applied in areas such as Production Organization, Quality Control or Maintenance Management.

# 5 Conclusion

The technological evolutions of Industry 4.0 arise as a response to new manufacturing and planning challenges, allowing the implementation of Smart Factories. This paper describes an SMS Laboratory, developed and implemented in the DPS at University of Minho, Portugal, to reproduce the manufacturing environment of a Smart Factory, with high flexibility in terms of reconfiguration (e.g. layout, products and processes).

The pilot test carried out obtained clearly positive feedback revealing that, with some changes (already underway, to make the experience more dynamic and maintain the focus and motivation of those involved), the entire system can be, as intended, used by students, constituting an active learning experience in the broad area of SMS. The authors acknowledge that the fact that it has only been possible to carry out a pilot test is a limitation of this study, which would require a greater volume of feedback.

By being exposed to hands-on activities and learning-by-doing principles, students will be able to witness/understand how a Smart Factory should work. The expected learning outcomes include: recognize key functional areas of MPC systems; understand the techniques and models used in MPC functional areas; implementing the techniques and models used in MPC functional areas; implement production planning and control systems in industrial environments; defining appropriate configurations for different industrial environments and with different requirements; understand the importance of information systems in the efficiency and competitiveness of organizations; apply skills acquired for the selection, evaluation and implementation of computer applications to support manufacturing planning and control systems.

The way in which the competences developed by students in this type of experience (especially in terms of technical competences) are assessed, as well as the collection of feedback on the same, is not yet completely defined, but will probably include an individual summative mini-test and a short survey, respectively. A brief workshop after the session in the laboratory is also an excellent and effective way to gather students' feedback.

**Acknowledgement**

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# Active Learning in the development of Product Data Management competences in an Industrial Engineering and Management Master Program

Micael Gonçalves[1], Ivo Teixeira[1], Paulo Martins[1], Guilherme Pereira[1]

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

Email: id6780@uminho.pt, pg42919@uminho.pt, pmartins@dps.uminho.pt, gui@dps.uminho.pt

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**Abstract**

Product Data Management (PDM) is a crucial function within the Manufacturing Planning and Control area, as it should provide reliable information for the other functions of that area. Thus, the development of PDM competences in Industrial Engineering and Management (IEM) programs is a matter of utmost importance, especially given that more and more companies must deal with high product diversity and customisation. Furthermore, today's Industry 4.0 context has led to a dramatic increase in the amount of information on products and functionalities inherent to Smart Factories, emphasizing even more the PDM importance. The objective of this paper is to describe and analyse the PDM teaching approach adopted in 2022/23 by the teachers of the Production Information System course unit of the IEM Master Program at University of Minho, in terms of technical and transversal competences development. The course unit consists of two parts, both incorporating active learning elements. The first part is about PDM fundamentals and uses a mix of expositive teaching, think-pair-share, and hands-on activities. Right from the start, students are confronted with real industrial scenarios and must incrementally develop the corresponding PDM models. The second part consists of a team project (project-based learning, learning-by-doing). Each team selects a real product family and develops its PDM model by hand (using a proprietary graphic language). Then, using proprietary software, each team implements and demonstrates the correctness of its solution. In terms of findings, the students' marks (encompassing an individual test and project report/presentation/discussion) revealed a good level of competences development, both technical (mainly) and transversal. Informal feedback from students highlighted some limitations but was clearly positive. The institutional assessment report validated this perception by showing that the students rated as good both the pedagogical dimension of the course unit and the motivation to face the challenges set for them.

**Keywords**: Engineering Education; Active Learning; Project Approaches; Product Data Management; Manufacturing Planning and Control.

## 1 Introduction

Industrial organizations have been facing technological and organizational challenges related to the large number of different and customized products that they have to deal with since the ability to manufacture a large diversity of products is now a requirement for a large number of organizations (Martins et al., 2021).

Product Data Management (PDM) is the area of Manufacturing Planning and Control that represents, integrates, and manages the data about the products, from conception to manufacturing. It includes data about the engineering drawings, projects, product technical specifications, bill of materials, bill of operations, machine programs or instructions, among others (Liu & Xu, 2001; Martins et al., 2021; Sousa et al., 2009).

The ability to deal efficiently with a high diversity and customization of products in manufacturing systems depends significantly on the product data model used to represent each product and provide information to the manufacturing planning and control processes. Some authors, such as Gao, Aziz, Maropoulos, & Cheung (2003), believe that PDM is the most important area within an organization or system. They call attention to the level of efficiency required to manage product data and argue that it has been increasing due to the need to launch new products to the market as quickly as possible, even more in the actual context of Industry 4.0, since the quantity of information and functionalities increased to implement Smart Factories (Guo et al., 2022).

Given the relevance of this subject, the Department of Production and Systems (DPS) of the School of Engineering of the University of Minho (UM), in Portugal, has carried out several research and development projects in this field and developed a new generic product data model called GenPDM (Generic PDM). GenPDM is a “flexible and easy to use” model capable to automatically generate information about each product - including information to characterize the product, its bill of materials, bill of operations and all remaining information required by different processes implemented in the organization. The information of each product is generated based on generic structures and rules defined by users of each organization, for each product family (Gomes et al., 2009; Martins & Sousa, 2013).

The Industrial Engineering and Management Master Program (MEGI) is a two-year master’s degree program of UM and one of the main courses in the DPS. The 2nd semester of the 1st year has 6 courses units, among which Production Information Systems (PIS). The PIS course unit aims to develop Product Data Management competences in MEGI students. The PIS syllabus includes the presentation and teaching of different product data models, in particular the GenPDM model (University of Minho, 2024).

Research in engineering education was shown the effectiveness of active learning and project-based learning (PBL) approaches to improve student’s learning ability in different subject matters and to develop transversal competences of project management, autonomy and communication (Christie & Graaff, 2016; P. Guo et al., 2020; Lima et al., 2007; Powell et al., 2003), making these approaches popular in engineering education (Kolmos, A., & De Graaff, 2014; Sousa et al., 2023). Over time, several examples can be identified in engineering education of different learning approaches and practices worldwide, as published in the MIT report ‘The Global state of the art in engineering education’ (Graham, 2018).

Over the last two decades, DPS also has been applying and testing several active learning and PBL approaches in its main Industrial Engineering and Management (EGI) programs, in different curricular years and course units, where each approach has its own characteristics (Sousa et al., 2023). An example refers to the PIS course unit since the teachers applies active learning principles to develop student’s Product Data Management competences for their professional lives. The application of these principles in PIS is particularly important because most of the program contents refer to generic concepts and tools that are not easily understood if they are not applied by the students.

The aim of this paper is to describe and analyse the teaching approach, from a conceptual and operational point of view, adopted by the teachers of the PIS course unit in the academic year 2022/2023.

The paper is structured in five sections. Section 2 presents the methods used to carry out this work. Section 3 presents and describes the teaching approach applied in the PIS course unit. Section 4 discusses the main results and limitations of the adopted approach. Section 5 presents the final remarks of the paper.

## 2 Methods

The development of this paper considered the official document describing the PIS course unit and the respective institutional assessment reports. The official document identifies the most relevant information of the course unit, namely general information (such as the course unit designation, main scientific area or number of hours), key learning outcomes, program summary, bibliography, teaching methods and assessment model. The institutional report provides information about the overall satisfaction level of the students. Furthermore, the analysis of the teaching approach (section 3) and discussion (section 4) was led by the teachers of the course unit with the support of the remaining authors, and taking into consideration the feedback given by the students (feedback collected informally throughout the course unit).

The teaching approach described in the next section has been applied in the PIS course unit for the last 10 years, not only in the MEGI Master Program but also in the Engineering and Operations Management Master Program (MEGO). Over the last years, some adjustments and changes have been introduced to improve the outcomes of the course unit. This paper describes the teaching experience during the academic year 2022/2023 (the last edition considering the date of this paper) in the MEGI Master Program as it is the main course of DPS (however, the teaching approach and results are similar at MEGO Master Program). Every academic year the project is planned by the coordination team shortly before the course unit classes start to define conceptual and operational aspects, objectives and schedule important dates (milestones, deliverables, etc.).

The characterization and analysis of the teaching approach applied considers the following parameters: (i) number of ECTS (European Credit Transfer and Accumulation System), (ii) duration, (iii) curricular year, (iv) different teaching methods of the course unit, (v) number of projects with an industrial organization involved, (vi) numbers of students involved, (vii) number and size of teams, (viii) size and role of the teachers, (xii) premises of the project, (xiii) number and type of milestones, (xiv) number and type of deliverables, (xv) assessment model and (xvi) students satisfaction level. The information of the last parameter was mostly gathered from the feedback collected and institutional assessment reports.

# 3 Analysis of the Teaching Approach

This section describes and analyses the PIS course unit, according to the parameters defined in the previous section. Furthermore, it addresses other information, namely technical and transversal competences developed during the course unit.

The PIS course unit is integrated in the 2nd semester of the 1st year of the MEGI Master Program. The PIS's main scientific area is Industrial and Systems Engineering, and (i) holds five ECTS, (ii) lasts one semester, and (iii) has 45 hours of classes and 95 hours of autonomous work. All classes are presential. In the academic year of 2022/2023, from mid-February 2022 to May 2023, 49 students were registered in the PIS course unit.

The teaching approach applied in the development of Product Data Management competences in the PIS course unit considered two main parts. The first part consisted of a set of seven theoretical and seven theoretical-practical two-hour classes, over seven consecutive weeks. In the first part, the main contents of the course unit were presented. In the theoretical-practical classes, a set of real case studies from different industries was selected to apply the knowledge gathered. The case studies selected were shoes, wood cabinets, metal pipes and concrete beams. This part considered a more traditional and expository teaching approach, even though some active learning principles were used in the case study discussions, such as Think-Pair-Share (e.g. about product diversity / customization and PDM role) or Hands-on (e.g. students were provided with a real product – an electric lantern – so they could disassemble it and create the respective bill of materials and bill of operations). At the end of the first part, students were assessed based on an individual written test.

The second part of the part of the course unit was a project, which constitutes the main focus of this paper. The main objective of the project, in terms of technical competences, was to represent from scratch a family of products with the GenPDM concepts and tools presented in the first part of the course unit.

The project last eight weeks and has four main stages (Figure 1). The moments marked in the figure are not intended to constitute rigid dates for the completion of each phase, serving mainly for students' teams to understand what is expected in each phase and to be able to monitor their progress. In fact, at certain times, different teams may not even be at the same stage of the project.

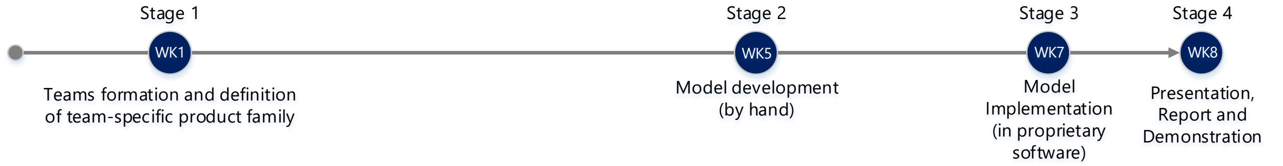



Figure 1. Phases of the Project

Students had four hours of weekly contact sessions, organized by team meetings and where the teachers supervised and supported the execution of the project. Additional support was also provided outside these periods, especially through presential and online meetings with each group. In the academic year of 2022/2023, the coordination team of the project was composed of the two teachers of the course unit.

The following paragraphs describe each stage and the assessment model of the project.

Stage 1: Teams formation and definition of team-specific product family

In the first stage of the project, the students organized themselves into seven teams of five or six students (each team could have a maximum of six students). Of the 49 students registered in the course unit, only 41 carried out the project (eight students were in Erasmus mobility).

After that, each team started working in its project. The first task for each team was to define a specific product family to represent and the set of options (diversity) that would be considered in the product family. This stage is particularly important since it influences the way how the remaining tasks of the project will be carried out, and also the complexity of executing them. The following guidelines were given by the teachers:

- Try to choose an example of an industrial organization where the team could have access to the needed information. Alternatively, each team could select freely an example but that can make access to accurate information more difficult; for instance, it is simpler to collect the customization options of a particular product family of an industrial organization than to identify which customization options make sense (with no actual real context). Moreover, all projects that are carried out in partnership with industrial organizations are always a good opportunity for both students and companies to share knowledge. In the edition under study, four of the seven teams developed the project using examples provided by industrial organizations, namely cardboard boxes, cabinets, electrical walls and flatware.
- Avoid large project scopes. The objective of the project is to evaluate the ability of each team to apply the concepts and tools learned in the course unit, so they should focus on simple and single examples for each point instead of complex and multi-examples applying the same concept or tool.

Besides that, students were also advised to define quickly the project scope in order to avoid delays in the remaining tasks of the project, and, consequently, extra working time outside of class hours. This stage took between one to two weeks.

Stage 2: Model Development (by hand)

The second stage consisted of the development of a model to represent the product family and customization options defined in the previous stage, using the GenPDM concepts and tools. GenPDM includes a graphical representation language that was used by students to represent each model. Figure 2 shows a Product Data Model for cardboard boxes developed by students.

Each team started this stage once the product family was defined and each team should have the model defined until week 5 of the project. The role of the teachers during this period was to give technical support and clarify doubts of each group, and not to support the management of each team.

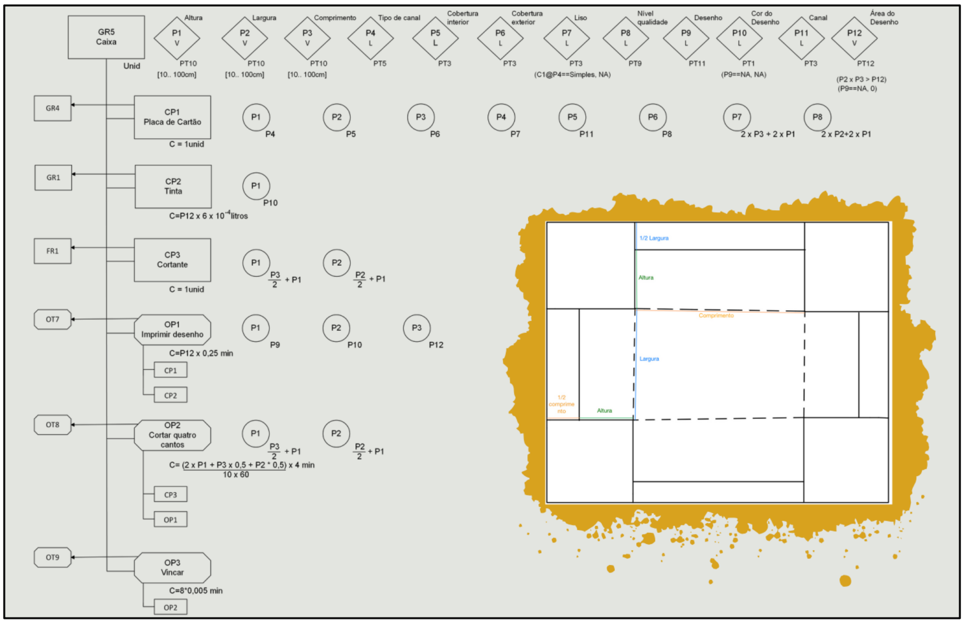



Figure 2. Example of a Product Data Model for cardboard boxes developed by students

<u>Stage 3: Model Implementation (in proprietary software)</u>

The third stage consisted of implementing the model (defined in the previous stage) in a specific software, the Smart Manufacturing System (SMS) software. This software used in this stage was developed at DPS-UM and that uses the GenPDM concepts and tools to represent all information about products. Besides PDM, the SMS software has more functional areas and processes implemented that require a huge amount of information. Figure 3 shows an example of the software interface with the Product Data Model of cardboard boxes.

This stage started at week 5 and took until week 7; therefore each team had a quite short time to represent their model in the software (it was their first contact with the software and there was little documentation available). To overcome this issue, at week 4 the software was installed on one computer of each group, and three hours of training program to all students on how to use the software were provided. During the training program, all teams followed the representation of a GenPDM model in the software, considering as an example a family of sport shoes (as this example has already been used in the first part of the course unit). This session applied a hands-on-learning approach since students were watching the representation of the model in the software and, at the same time, replicating the same sequence of steps on their computers.

After that, each team started the implementation of their own case studies in the software. At the end of week 7, all teams had to send the software database (project deliverable 1).

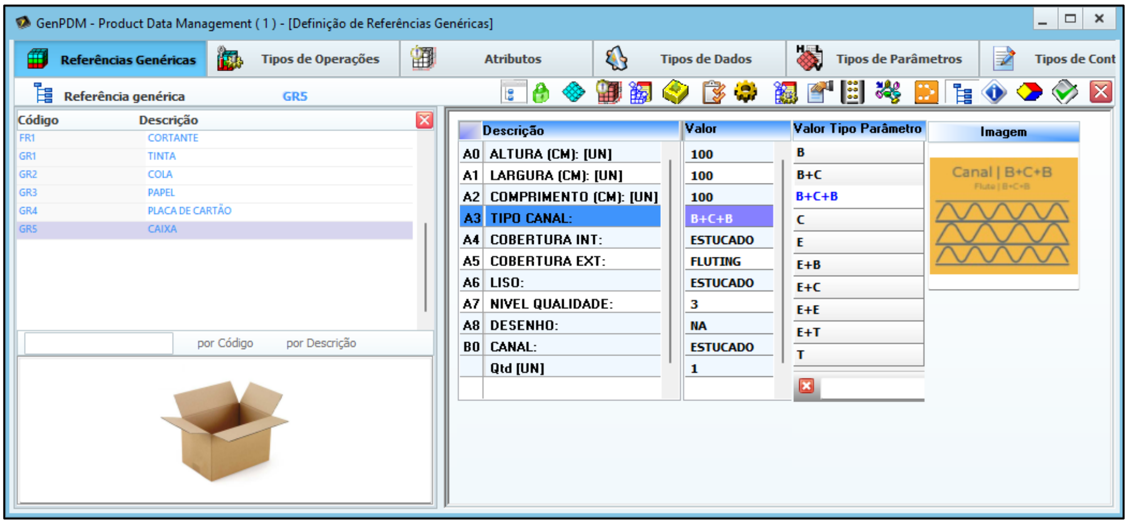


Figure 3. Example of the software interface with the Product Data Model of cardboard boxes

<u>Stage 4: Presentation, Report and Demonstration of Planning and Control Outcomes</u>

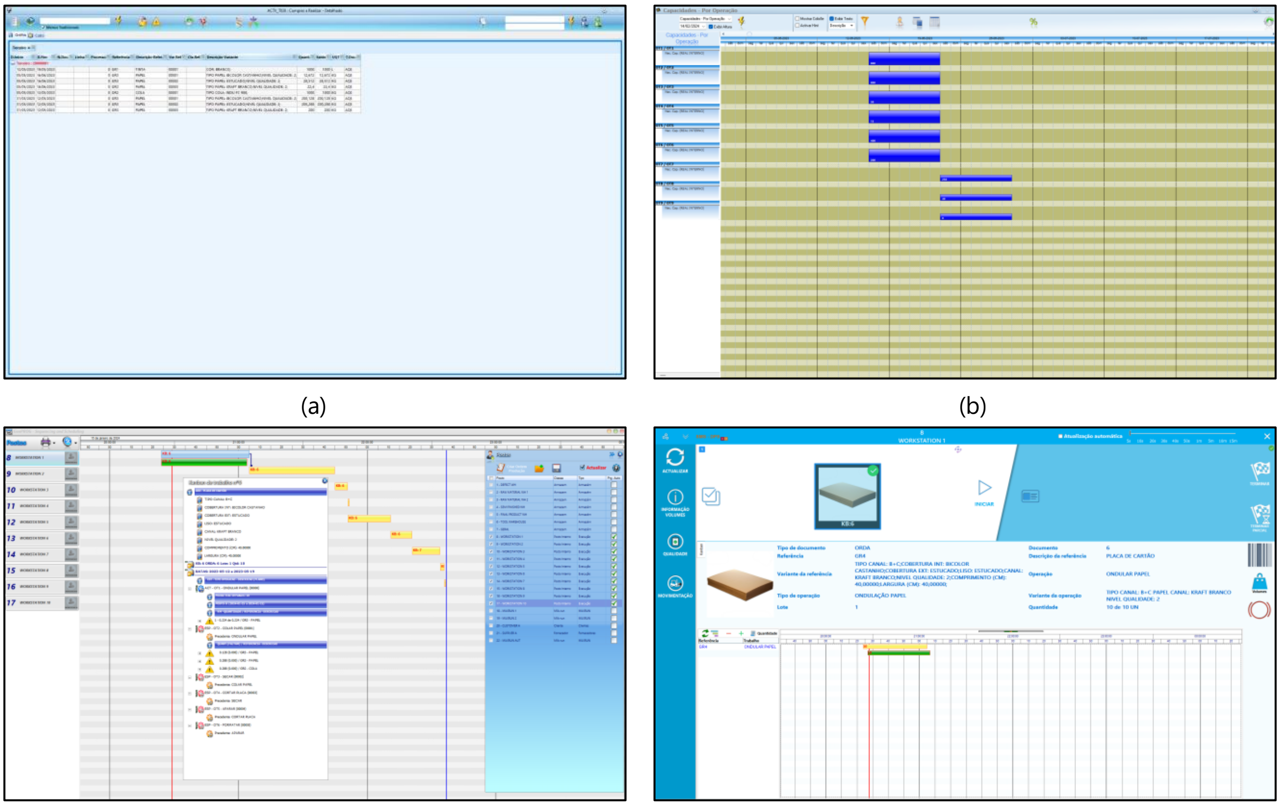
In the final week of the project (week 8), each team did a ten minute presentation to the remaining colleagues and teachers. Students were requested to present their models, the main novelties and limitations of their solution and the major difficulties during the project. Each presentation was followed by a five minutes discussion where at least one question was requested from each team, in addition to questions from the teachers. At the end of the day, each team had to send the document used for the presentation (project deliverable 2).

Additionally (also at the end of week 8) each team had to prepare and send a written report (project deliverable 3). In this report, students had to present their models and critically review the entire process, namely identifying the novelties, limitations, and restrictions, not only of their model, but also regarding the GenPDM model and the SMS software. A template for the report has not been provided, but the teachers encouraged students to deliver concise and short reports.

As referred previously, a PDM model should provide all information required for the manufacturing planning and control processes. Therefore, in stage 4, the teachers used one of the case studies developed by the students, to show, in the SMS software, the impact of that model in the outcomes on the manufacturing planning and control processes. That is the reason why the database (project deliverable 1) was sent one week before the remaining deliverables (to give teachers time to prepare for this session).

Figure 4 shows some examples of SMS software interfaces based on the Product Data Model of cardboard boxes. Figure 4(a) shows the purchase orders suggested by the SMS software to satisfy all customer orders defined in the system. Figure 4(b) shows the capacity requirements to satisfy the customer orders. Figure 4(c) shows the interface of a manager/planner that includes all information of each manufacturing batch (e.g. components needed, operations and their status). Figure 4(d) shows the interface to be installed in a workstation and that displays all information required to execute each job (e.g. information about the product to be manufactured, operation, quantity).

This session was presented by the teacher after all team presentations and took approximately one hour. It is important to note that although students did not have an active role in the preparation of this session, they had the opportunity to see and understand the impact of their models (and the decisions they made throughout the previous stages) on the outcomes presented. Moreover, students have also the opportunity to see the application of some methods and algorithms that have been learned in other course units, such as Manufacturing Planning and Control (a course unit of the Bachelor in Industrial Engineering and Management).



(a) (b) (c) (d)

Figure 4. Examples of SMS software interfaces in different manufacturing planning and control processes, based on the Product Data Model of cardboard boxes

Assessment Model

The assessment model of the PIS course unit considers both parts. The first part is evaluated by an individual written test and the second part, that is, the project, is assessed based on: (i) the database that results from stage 3 (project deliverable 1); (ii) the presentation and discussion of stage 4 (project deliverable 2); (iii) the written report of stage 4 (project deliverable 3). There is no peer assessment to distinguish, within each team, individual performance in the project, but its application in future editions is being discussed.

The weights assigned to each item have been changing over time. In the edition under study, the written test counted 65% and the project counted 35% (database – 10%, presentation – 10% and report – 15%). The assessment considered different criteria such as technical issues, structure of each document, communication/writing skills, creativity, among others. The average score of the all-individual tests was 77% and for all-team projects was 78%.

# 4 Discussion

This section presents a critical review of the: (i) teaching approach applied, (ii) feedback gathered informally from the students, and (iii) results of the course unit institutional assessment reports.

The students' feedback gathered informally throughout the course unit was positive, but to collect more detailed feedback, there was a 30-minute session at the end of the project where all teams were invited to share their opinions and new ideas about the course unit. The students referred repeatedly that the project was very important to learn the contents of the course unit and helped them to understand the potential for industrial organizations of the concepts and tools learned. Besides that, they also mention that the project helped them to recognize the importance of product data in the outcomes of manufacturing planning and control processes.

On the other hand, students also called attention to the high number of deliverables of the course unit and suggested that the SMS software could be installed on the computer of all students (instead of just one per team) to allow all students to participate and work in parallel. The teachers explained that the SMS software was installed in just one computer to avoid problems managing the database of each team (since the software database is designed to be stored in a data centre where several users could be linked, but it is not possible to implement a similar technological infrastructure in the university).

The institutional assessment reports of the course unit also showed interesting results. At the end of each semester, students are requested to reply to a quick questionnaire about how each course unit worked. The questionnaire of the PIS course unit was replied to by 27 students and the results are shown in Figure 5. The institutional assessment report shows that the assessment of the teaching dimension of the course unit was very good (4.2 out of 5 points; 84%). The motivation of each student to deal with the challenges they have to face, namely the project, was also very good (4 out of 5 points; 80%). All four dimensions improved compared to the previous year. Finally, the students' average grade in the curricular unit was 78% (15.5 out of 20; individual test and project), also demonstrating the success of the approach applied.

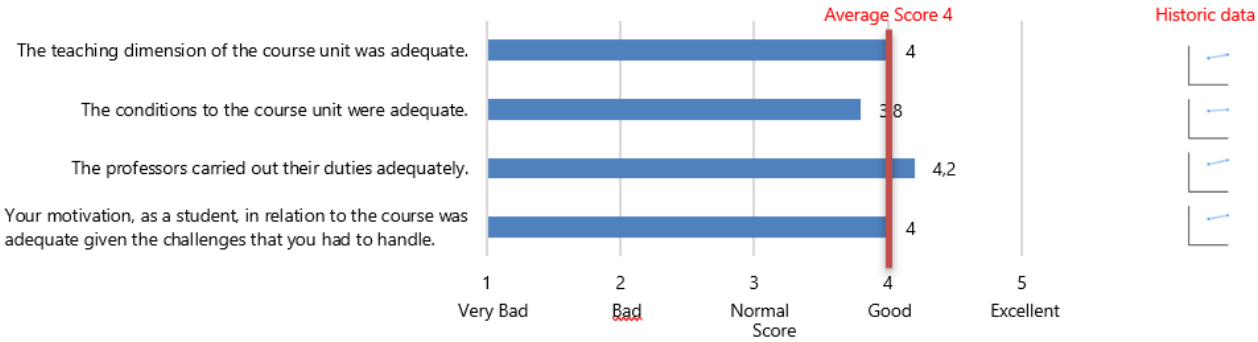



Figure 5. Results of the institutional assessment reports (PIS course unit; MEGI master's degree, 2022/2023 academic year)

# 5 Conclusion

This paper describes the active learning approach applied in the PIS course unit of the Master's in Industrial Engineering and Management (MEGI) at University of Minho, which has been developed and improved over the last few years, based on the particularities of the educational context of the course unit. The approach adopted presents good results both in the development of technical and transversal competences and in students' satisfaction. Particularly, the development of Product Data Management competences allows students to go deeper into the concepts and tools proposed which will be important for their professional careers.

To support the results of this study, future editions of the PIS course unit should collect more qualitative and quantitative evidence about their strengths and weaknesses, which may lead to improvement in the conceptual and operational aspects of the active learning approach applied.

Finally, it is important to note that the active learning approach described in this paper has been considered efficient over time in this course unit due to ongoing research on active learning, project-based learning and

Product Data Management carried out in the department of the faculty (either in the development of new models and software). The implementation of a similar approach in other educational environments may lead to different challenges that should be analysed carefully.

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# Developing Coping Skills in Engineering Students to Overcome Emotional Challenges: A Participatory Approach from Project-Based Learning

Sandra Liliana Rojas Martínez[1], Sonia Esperanza Monroy Varela[1]

[1] Universidad Nacional de Colombia, Facultad de Ingeniería, Departamento de Ingeniería de Sistemas e Industrial. Campus Bogotá, Colombia.

Email: slrojasm@unal.edu.co, semonroyv@unal.edu.co

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**Abstract**

The project aims to enhance resilience and coping skills in university students to overcome emotional challenges by employing the Problem-Based Learning (PBL) approach with a focus on Participatory Action Research (PAR). This paper exclusively addresses the design of the pedagogical intervention. The target population comprises students admitted to the Systems and Computing Engineering and Industrial Engineering programs through special admissions at the Universidad Nacional de Colombia, Faculty of Engineering, in Bogotá D.C. and Cundinamarca. This group has an increasing prevalence of emotional problems among young university students, attributed to specific socioeconomic and cultural factors. The project is structured around a comprehensive and participatory methodological process, engaging youth in problem identification, solution design, intervention implementation, and results evaluation. Active youth participation is prioritized across all project stages, fostering empowerment and commitment. The methodology includes phases such as problem identification and definition, intervention planning, implementation, evaluation and reflection, adjustments and improvements, results consolidation, dissemination and socialization of learning, empowerment and continuity, and continuous monitoring. A multidisciplinary team collaborates with young individuals throughout each project phase. Intended Learning Outcomes (ILO) include the clear identification of emotional challenges, the design and implementation of effective interventions, bolstering resilience and coping skills, and ensuring the long-term sustainability of initiatives. Emphasis is placed on sharing learnings and results within the university community to promote replicability and the proliferation of best practices. This project addresses the emotional health issues in university students by providing practical tools and strategies to confront and overcome emotional challenges, thereby fostering their well-being and holistic development. Its participatory and collaborative approach positions it as a significant contribution to active learning and mental health promotion in university contexts.

**Keywords**: Project Based Learning (PBL); Engineering Education; resilience and coping skills; Participatory Action Research (PAR).

## 1 Introduction

This project aims to promote coping skills in young students who enter through the special mobility admission program (Special Admission Students) of the National University of Colombia, specifically in the undergraduate programs of Systems and Computing Engineering and Industrial Engineering at the Bogotá campus. The goal is to help these students overcome emotional challenges through an educational intervention supported by the Problem-Based Learning (PBL) approach and Participatory Action Research (PAR).

The project addresses the persistent and growing challenge of emotional health, characterized by a significant increase in the incidence of emotional health problems such as anxiety, depression, stress, and feelings of hopelessness. Additionally, it seeks to tackle the lack of in-depth training programs to promote the necessary skills for students to confront their emotional challenges effectively. Without such training, students may be inclined towards negative coping strategies, such as the consumption of psychoactive substances and engagement in risky behaviors. During adolescence, a crucial phase in individual development marked by significant biological, psychological, and social transformations, coping skills —or coping strategies— that integrate methods and techniques to handle stressful situations, emotional problems, or life challenges acquire special relevance (Frydenberg, 1997).

The Lazarus and Folkman model (1984) highlights, in the understanding of coping, how the changing efforts to manage excessive demands distinguish between problem-focused and emotion-focused coping. It also identifies different categorizations (Crespo and Cruzado, 1997). Frydenberg and Lewis (1996b) define three styles of coping: productive, non-productive, and other-oriented.

Studies point out gender differences in coping strategies. For example, women are more prone to non-productive strategies, while men are more likely to ignore problems (Frydenberg and Lewis, 1994, 2000; Hampel and Petermann, 2005; González et al., 2002). These aspects are compiled in a study that relates coping to the personal well-being of students, concluding that coping strategies focused on the positive are associated with greater personal well-being (Viñas et al., 2015).

Two coping strategies have been selected to be implemented in the pedagogical intervention: Self-Instruction Training and Stress Inoculation Training.

**Self-Instruction Training**

Self-instruction training is a metacognitive coping strategy that involves thinking about our thoughts, actions, and behaviors. It focuses on learning to give ourselves instructions to regulate our behavior. This strategy was proposed by Meichenbaum in the 1940s. Deficits that occur when a problem arises can be due to issues in understanding, production, or mediation. In this workshop, it is considered relevant to address the concept of self-regulation, which can be learned through the following phases:

- Adult cognitive modeling.
- Participant cognitive modeling.
- Self-instructions.
- The fading of aloud instruction.
- Internal self-instructions.

Likewise, the functions to be executed are preparing to face the situation, focusing attention on the task, guiding behavior, providing reinforcement, evaluating the results, and reducing anxiety.

The procedure includes seven stages:

- Carry out self-records: Evaluate how the student is performing the activity, maintain useful actions, and reduce non-useful actions.
- Generalize good actions: Ensure that self-instructions lead to the generalization of good actions.
- Identify situations and components: Recognize situations and components according to the context.
- Focus attention on the problem: Answer the questions: What should be done? and, how should it be done?
- Define specific rules: Be attentive to different response possibilities or alternative solutions.
- Handle errors: Identify failures, their causes, and their consequences.
- Self-reinforcement: Identify the efforts made and the results achieved.

**Stress Inoculation Training**

Stress Inoculation is akin to a vaccine; its purpose is to improve coping responses in low-intensity situations to prepare individuals for high-intensity situations. It is based on the following models: the Transactional Stress Model (Lazarus and Folkman, 1984) and the Reciprocal Determinism Model (Bandura, 1977), where external environmental demands are high, and individuals cannot respond with the resources they have. Additionally, it incorporates models of cognitive-affective processes, where the origin of stress is influenced by various interrelated elements, such as cognitive, affective, physiological, behavioral, and environmental factors, as well as traumatic or stressful events that can invalidate fundamental beliefs about the world or the meaning of life.

This training integrates a series of techniques to address four types of stress:

- Acute time-limited stressors: These include students who develop anxiety related to specific events, such as giving public presentations, taking exams, or completing classwork.
- Sequential stressors: This occurs when a series of events are chained together, such as economic situations preventing a student from traveling to the university, leading to missed classes, poor nutrition, health problems, loss of concentration and attention in academic aspects, poor evaluations and assessments, and eventually, the loss of the subject and the semester.
- Chronic intermittent stressors: This affects individuals with recurring diseases who must retake tests on fixed dates over periods of years and months to determine their health status.
- Continuous chronic stressors: This includes exposure to one or more difficult situations for many years, such as chronic pain that persists continuously without a cure.

The purpose of this type of training is to change disturbing imaginations, images, and self-verbalizations through self-regulation, replacing them with functional imaginations, images, and self-verbalizations. Additionally, it aims to change maladaptive behaviours to adaptive ones and replace negative cognitive structures with alternative ones. These objectives are achieved through three phases: Conceptualization, Skill Acquisition and Training, and Skill Application, which are described below.

*Conceptualization:* involves evaluating and training self-observation. This phase includes defining problems in concrete, specific, non-evaluative behavioral terms. Each problem must be defined independently and separately, with an exhaustive search for internal and external variables that have created and maintained the problem. It also involves identifying coping difficulties and potential deficits in specific skills or cognitive/behavioral/emotional interferences. The reconceptualization of the problem should be manageable and credible for the student, distinguishing changeable stressors from unchangeable ones, and dispelling beliefs and myths related to emotional responses and reactions to stress.

*Acquisition and training of skills:* This integrates the following elements.

- Imagination or live exposure techniques: Used for phobias, fear, and avoidance.
- Modeling or Graduated Exposure: Gradual exposure to challenging situations.
- Operant Techniques: Behavioral reinforcement strategies.
- Problem-solving: Breaking down situations into manageable units and developing action plans.

The steps involved

- Situation to resolve, analysis of requirements to solve the situation, divide the situation into units, and prepare the action plan.
- Self-reinforcement training is carried out using cognitive Self-Instruction, this is when disconfirming evidence is considered.
- Self-Instruction to confront the stressor (preparation: focus on what needs to be done and not confront the stressor. In this case, self-instruction is used to control the stress reaction, perform a non-catastrophic interpretation, reinforce the trained skills, and then the coping with the discomfort).
- Self-Instruction guides to stay in the situation, and assessment of efforts, this implies Self-Instruction to evaluate what has worked, progress, and self-recognition). It is important to know the different strategies such as:
    - Strategies to Control Emotional Activation such as (Relaxation, deep breathing, and detecting moments before activation to use them in moments of tension).
    - Behavioral strategies (Imagination or vivid exposure techniques: when you have a phobia, fear, avoidance; Modeling, Graduated exposure; operant techniques; problem solving: Moments of pain pass, it occurs at different times; train habits and behaviors.
    - Palliative Coping Strategies. To mitigate discomfort in unavoidable or difficult-to-control situations. Perspective Taking: when there is a feeling of helplessness, focus on the changes that are occurring, through contact with people in a similar situation.

*Application:* This phase has the following aims: putting the learned strategies into practice in real situations, checking their usefulness and effectiveness, and addressing problems that arise during implementation. To promote the application of coping strategies, self-instructions must be prepared for various moments, gradual exposure to different situations should be carried out from positive to negative, graduation with exposure in imagination or role-play should be implemented, coping strategies should be used to prevent relapses during high-risk moments for cognitive, emotional, or behavioral reactions, and attributions of self-efficacy should be promoted and reinforced. Finally, coping efforts and success, whether total or partial, should be assessed. For maintenance and generalization, generalization should be gradually worked on, encouraging the student to face different real situations and spacing out sessions to focus only on maintenance sessions. Other relevant aspects should also be included in maintenance, and students should be encouraged to train others in similar circumstances to solidify their learning.

Considering that the Participatory Action Research (PAR) approach is used to comprehensively address this problem in a participatory manner, involving students in identifying solutions, implementing effective strategies, and continuously evaluating to improve the emotional and life health of the student population in the university context. The research question posed is as follows: *How can an educational intervention be designed to promote coping skills among students in the (*Special Admission Students) *program of the Faculty of Engineering at the National University, aimed at addressing emotional challenges and supported by Participatory Action Research (PAR) and Problem-Based Learning (PBL) approach?*

Concerning the methodology, research is mixed, incorporating both quantitative and qualitative methods. The research type is descriptive and quasi-experimental, without a control group or random selection. The project will be executed through a participatory-collaborative action research process, with students actively participating in defining coping problems, designing solutions, evaluating results, and incorporating didactic and pedagogical strategies to strengthen coping skills.

# 2 Scope

Emotional health problems have a significant impact on students' quality of life, affecting their interpersonal relationships, academic performance, and ability to achieve their potential. It is important to highlight that activities promoting soft skills are included in students' academic training programs. In the Faculty of Engineering at the National University of Colombia, training programs for skills development have been provided. However, teaching and learning activities specifically aimed at effectively addressing emotional challenges have not been incorporated, potentially leading to the adoption of negative coping strategies. Therefore, there is a clear need to designed effective educational interventions. Consequently, the objective is to design an educational intervention that promotes coping skills among students in the Special Admission Students program of the Faculty of Engineering at the National University, addressing emotional challenges through a combination of Participatory Action Research (PAR) and Problem-Based Learning (PBL).

## 2.1 Methodological Design of Educational Intervention

### 2.1.1 Aims

Below are the general and specific aims intended to be achieved through the educational intervention: To promote coping skills among (Special Admission Students) enrolled in the undergraduate programs of Systems and Computing Engineering and Industrial Engineering at the Bogotá Campus of Universidad Nacional de Colombia, helping them overcome the emotional challenges they face through an educational intervention supported by the Problem-Based Learning approach and Participatory Action Research.

**Specifics**

- To identify the emotional challenges and the coping mechanisms characteristic of special admission students by implementing standardized tests designed for this purpose.

- To plan the educational intervention, which includes defining specific objectives for the strategies and activities to be undertaken by special admission students, outlining strategies for enhancing coping skills, and creating a detailed action plan.
- To implement the strategies and activities within the framework of the Educational Intervention following the stages defined during its planning.
- To evaluate the educational intervention by integrating feedback from students using defined metrics, leading to the formulation of improvements in the intervention. This step aims to continuously adapt the intervention to achieve effective results.
- To reflect on the effect of the intervention on the quality of life of special admission students, supporting argumentation and interpretation of the results and information, as well as observing changes in behavior and engaging in joint reflection on what works and what needs to be adjusted.

### 2.1.2 Intervention Protocol

The intervention protocol described below includes the actions and procedures to be carried out to meet the aim, the strategies, the methods and tools to be used, the steps to be followed in each stage of the intervention, the procedures for collecting and analyzing data, and the criteria for evaluation and progress monitoring. This is done to ensure consistency, quality, and effectiveness of the intervention, as well as to facilitate replicability and comparison of results in similar studies. In response to the research question, the intervention protocol incorporated in the methodological design are described in detail below. Actions and products associated with each of the aims are presented in the following Table 1.

Table 1. Intervention Protocol.

| Aim | Actions | Products | Week |
|---|---|---|---|
| 1 | • Perform the Coping tests (Frydenberg and Lewis 1996b). | • Document summarizing challenges and characterization of the type of coping used in students before the educational intervention. | 1 |
| 2 | • Design Workshops, training sessions, group activities to strengthen coping skills. | • Action plan with objectives and strategies.<br>Record of Intervention Sessions.<br>Educational Didactic Material (Workshops, support documents for training, rubrics for assessment and evaluation of activities) | 2 |
| 3 | • Train students in activities that facilitate the strengthening of coping skills in a sustainable way.<br>• Implement the workshops using the educational teaching material that was designed in the intervention planning stage. | • Record of training activities. | 3 |
| 4 | • Consolidate the results in easily accessible digital media, so that they can be transferable to other students; These digital media include educational materials and sustainable strategies to disseminate the benefits obtained.<br>• Disseminate the learning that was the result of the special admission students participatory action research with the university community.<br>• Establish a continuous monitoring system to evaluate the short-term effectiveness of the educational intervention and adjust as necessary. | • Training activity plan.<br>• Document of good practices and lessons learned.<br>• Dissemination report and presentations.<br>• Continuous monitoring report. | 4 |
| 5 | • Analysis of the Results.<br>• Joint reflection on what worked or what needs to be adjusted. | • Report on opportunities for improvement and results of joint reflections. | 5 |

#### *2.1.2.1 Definition of Strategies (E), Intended Learning Outcomes (ILO) and procedures for data analysis (PDA)*

Three strategies were developed as part of the educational intervention. These strategies and procedures are grounded in psychological principles related to metacognitive learning, emotional self-regulation, reflection, critical analysis, and decision-making, all of which are fundamental aspects in the development of coping skills among engineering students. Tables 2 to 4 provide details on the name of each strategy, the instruments to be used, the Intended Learning Outcomes (ILOs), and the procedures for data analysis. The strategies are designed to help Engineering students at the Universidad Nacional de Colombia manage emotions within the university academic context. These strategies objectives to prepare students to successfully navigate academic situations that elicit various emotions, such as delivering oral presentations of their research to the community and engaging in problem-solving activities.

Table 2. Holistic approach for activating coping skills in engineering students' strategy.

| **Strategy/Instrument Denomination: Holistic approach for activating coping skills in engineering students" / Coping Scales Test .** | | |
|---|---|---|
| **At the end of the strategy, students will be able to** | **Teaching Activities TA/Learning Activities LA /Evaluation Activities EA** | Procedures for Data Analysis - **PDA** |
| • Identify specific coping strategies.<br>• Distinguish specific and general coping, allowing for a differentiated understanding of how they deal with situations versus how they deal with various situations in their daily lives. | TA: Preparation of the presentation and documentation of the types of coping and the ACS explanation of the test to be used in the students.<br>LA: Participation at the end of the presentation with questions about any doubts that may arise regarding the presentation of the ACS test.<br>EA: Presentation of the ACS test by the student. | • Identification of the specific coping strategies used by students between 16 and 17 years of age, through the analysis of the responses (ACS) of Frydenberg and Lewis (1996b) and analysis of the ACS subscales to understand the diversity of strategies coping strategies available, from approaches focused on problem solving to those focused on emotional regulation.<br>• Evaluation of the effectiveness and frequency with which different coping strategies are used, detection of adolescents' preferences and abilities to face challenges.<br>• Integration of ACS test results with other assessments and observations to obtain a holistic view of coping skills. |

Table 3. Self-instruction training for anxiety management in solving problems strategy.

| **Strategy/Instrument Denomination:** "Self-instruction training for anxiety management in solving problems"/ Workshop 1 - ASC, Self-assessment Rubric, Knowledge Test, Semi-structured interview. | | |
|---|---|---|
| **At the end of the strategy, students will be able to** | **Teaching Activities TA/Learning Activities/Evaluation Activities** | **PDA** |
| • Self-record their actions and thoughts while trying to solve a programming problem.<br>• Identify which actions and Self-instructions are effective and can be applied to different problems.<br>• Analyze the context of the problem to determine what actions are necessary.<br>• Establish rules that answer fundamental questions about what to do and how to do it in the context of the problem.<br>Identify errors, their causes, and consequences to learn from them.<br>• Apply Self-Reinforcement in your efforts and results in solving the problem. | Activity 1.<br>TA: Activity Design<br>• Adult cognitive modeling, which will be used to address the situation that the student faces when solving a specific engineering problem in the Computer Programming subject where he cannot understand the procedure statement, or he understands what the statement says but He does not know how to provide a solution, or he recognizes that he must apply techniques and procedures but he does not know which of them is appropriate and he does not know how to provide himself with the appropriate instructions for the technique or procedure that will adequately guide him to the solution.<br>• Participant cognitive modeling: in which the same previous situation is addressed, but an algorithm is if leads to the solution of the problem, the teacher points out each step and the student executes it until reaching the solution.<br>• Self-instructions: The student is given the same problem to solve where the variables and conditions are different, the algorithm that corresponds to the sequences of instructions leads to the solution, but in this case the student executes the instructions out loud.<br>• The Fading of the instruction out loud: When the sequence of instructions is performed mentally and leads to the solution.<br>• Internal self-instructions: When the student executes the sequence of solutions that leads to overcoming the problem through internal thought processing, where each step is indicated.<br>LA: The student develops the steps established in the Self-instruction training. | • Self-Assessment Rubrics: Which evaluates the student's performance in terms of emotional self-regulation, reflection, analysis, and decision making.<br>• Knowledge Test in the application of sorting algorithm.<br>• Reflective interviews integrate open questions so that participants reflect on their experiences, perceptions, thoughts, and emotions. In the context of coping and self-regulation, interviews can explore the strategies used to face challenges, the perception of the effectiveness of these strategies, and the learnings obtained. |

Table 4. Activate the ability to cope with anxiety situations in the academic environment strategy,

**Strategy/Instrument Denomination** : Activate the ability to cope with anxiety situations in the academic environment / Workshop 2 -includes Knowledge Test, Semi-structured Interview and Feedback Questionnaire

| At the end of the strategy, students will be able to | Teaching Activities TA/Learning Activities/Evaluation Activities | PDA |
|---|---|---|
| •Recognize the different types of stress, identifying how each one impacts the ability to cope and emotional management.<br><br>• Replace disturbing thoughts with functional ones and adopt adaptive behaviors in anxious situations through emotional and cognitive self-regulation.<br><br>• Apply strategies to control emotional and behavioral activation to mitigate discomfort and improve coping capacity according to the anxiety situation.<br><br>Integrate Self-instruction and Self-reinforcement techniques into the training process, strengthening the ability to face stressful situations effectively and proactively.<br><br>• Evaluate the effectiveness and usefulness of the strategies learned through practical application in real situations, identifying the positive impact on stress management and improvement in coping with academic and personal challenges. | Activity 1 Recognizing stressful situations in the academic context. (self-study)<br><br>TA: Microsite Design and Implementation – Activation of coping skills.<br><br>LA: The student goes through the microsite on foundations about the different types of stress and coping techniques.<br><br>EA: The student answers the questions associated with each of the thematic sections that are included in the microsite.<br><br>Activity 2 Role play of coping strategies. (team learning)<br><br>TA: Design of the different scenarios in coherence with the types of stress in the context of the Faculty of Engineering.<br><br>Sceneries<br><br>1. Acute Stress: A student must prepare and present a presentation on a complex topic to a demanding and critical audience within a very tight deadline. The student may experience intense anxiety, pressure, and nervousness due to the importance of the event and the limitation of time to adequately prepare.<br><br>2. Sequence Stress: A student experiences sequential stress when, after an intensive week of final exams, she receives news that her academic scholarship is at risk due to her poor performance in a specific subject. This situation adds to the accumulated pressure of exams and places additional stress on her financial and academic situation.<br><br>Chronic Intermittent Stress: An engineering student working as a research assistant. She faces periods of high work demand during the research project submission season, followed by periods of relative calm. This constant fluctuation between intense periods and less demanding periods contributes to chronic intermittent stress.<br><br>3. Continued Chronic Stress: This type of stress occurs when a student who lives in inadequate and noisy accommodation conditions experiences continued chronic stress. The lack of a quiet and conducive environment for studying affects her concentration and rest, leading to constant and prolonged stress that negatively impacts her well-being and academic performance over time.<br><br>LA: Students are organized into teams of 3 to 4 members, each of which is assigned one of the designed scenarios.<br><br>The members of each group act according to the roles that can be presented in the assigned scenario, identifying the emotional reactions that can occur and coping strategies.<br><br>After the simulation, the group members asked how they managed stress in the scenario and how they could improve in the future.<br><br>EA: Verification of the recognition of stress according to the case presented. Perception Test. | • Knowledge Test about types of stress and coping strategies<br><br>• Reflective interview integrates open questions so that participants reflect on their experiences, perceptions, thoughts, and emotions. In the context of coping and self-regulation.<br><br>Feedback questionnaires:<br><br>Where students complete after the activity to evaluate their perception of the development of the activity, their understanding of stress and coping strategies, and their self-assessment of their performance. |

#### 2.1.2.2 *Tools of the Educational Intervention*

Three tools are used during the educational intervention, these are: the first is for formal use for the identification of coping skills and is called the Adolescent Coping Scales - ACS, the second and third tools called workshops are built based on the existing information on the characterization of students, special admission programs and integrate specific tools for collecting information; Regarding these, their educational aim and the conceptual support on which they are designed are described.

- **The Adolescent Coping Scales (ACS)** Developed by Frydenberg and Lewis (Frydenberg and Lewis 1996b) they are a crucial tool for understanding and evaluating the coping strategies of adolescents, specifically those between 12 and 17 years of age. These scales consist of 79 closed items and one open final item, distributed in 18 subscales. Each item is evaluated on a 5-point Likert scale, reflecting the frequency with which the individual uses a specific coping strategy. The population is 18 students with an average age of 17 years old. One of the most notable aspects of the ACS is its distinction between two versions: one to assess specific coping and another to assess general coping. The specific version allows us to understand how the adolescent faces situations or problems, while the general version provides a broader vision of how the adolescent faces various situations in his or her daily life. The breadth of subscales on the ACS allows for the exploration of a variety of coping strategies, from problem-focused to emotion-focused approaches. This provides a holistic understanding of adolescent coping skills and can help design effective programs that promote resilience and emotional well-being at this crucial stage of development.

- **Workshop 1 – Coping Skills: Self-Instruction Training:** At the end of the first workshop, the student will be able to implement the Self-Instruction training strategy, which promotes coping skills in cases where there are deficiencies related to cognitive and metacognitive skills that prevent or limit behavior, emotional self-regulation, reflection, analysis, and decision-making to overcome situations satisfactorily.
- **Workshop 2 – Coping Skills: Stress Inoculation Training*:*** At the end of the first workshop the student will be able to face the situation of presenting to the academic community of the National University of Colombia the results of his research orally, through adequate management of his emotions acquired by their preparation and prior exposure to this type of situation.

### 2.1.3 Tools for Information Analysis

One of the tools used is ATLAS TI is a qualitative analysis software that allows you to organize, analyze, and visualize textual and multimedia data, facilitating the identification of patterns, themes, and relationships in large data sets. R is a free software and programming environment for the analysis of data statistics and visualization. It offers a wide range of statistical and graphical tools for data processing and the generation of predictive models., Monitoring System is a tool that allows you to supervise activities and providing reports.

## 3 Conclusions

The implementation of coping strategies contributes to improving the emotional well-being of students by providing them with tools to manage stress, anxiety, and other negative emotions effectively. By learning to deal with difficult situations more effectively, students experience an improvement in their academic performance by reducing the negative effects of anxiety on their ability to concentrate, remember, and make decisions. Coping strategies are useful in academics since they are fundamental life skills. By integrating these strategies into the educational curriculum, students are prepared to face the challenges and demands of everyday life more effectively. Educational intervention that teaches coping strategies contributes to the prevention of mental health problems in students by providing them with tools to manage stress, anxiety, and other emotional difficulties healthily and adaptively. This can have a long-term positive impact on your overall well-being.

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# Continuous Evolution of The Unified Platform of Active Methodologies (PUMA): Focus on Integration between Market and Academia

Simone B. S. Monteiro[1], Rodrigo P. Gomes[1], Luis Guilherme B. Monteiro[2], Ana Cristina Fernandes Lima[1], Everaldo Silva Junior[1], Gabriel de Lanna Fiuza Curi Garcia[3]

[1] Pós-Graduação em Computação Aplicada, Darcy Ribeiro, Universidade de Brasília, Brasil.
[2] Engenharia de Software, Faculdade do Gama, Universidade de Brasília, Brasil.
[3] Engenharia de Produção, Faculdade de Tecnologia, Universidade de Brasília, Brasil.

Email: simone_simao@yahoo.com.br, rodrpg23@yahoo.com.br, luisguilhermebm91@gmail.com, anacristina.limafernandes@gmail.com, everaldo.s.junior@gmail.com, gabriel.lanna@aluno.unb.br

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**Abstract**

The Unified Active Methodology Platform (PUMA) is a platform being developed by undergraduate students in Software Engineering and Design courses, with the participation of students and professors from Production Engineering and Applied Computing master's program at the University of Brasília. This project was supported by the Learning Program for the 3rd Millennium (A3M) in 2018, its conception year. Its focus is on capturing projects from various stakeholders and allocating them to Production Systems Projects disciplines, so that engineering students can present technological solutions. One of PUMA's objectives is to measure the effectiveness of Problem-Based Learning (PBL) methodology applied to the Production Engineering course at UnB, enabling students to acquire skills and knowledge necessary to meet market demands combined with academic knowledge. This article aims to present the continuous evolution of the PUMA Platform, focusing on updating functionalities and layouts implemented in its development process. The research has a qualitative approach and is classified as a case study. The results show that integration between different areas of knowledge is essential to ensure platform development, in order to find the needs of business managers and platform users.

**Keywords**: Active Methodologies; Problem Based Learning; Multidisciplinary; Project capture.

## 1 Introduction

The use of traditional teaching methodologies is employed by students in Higher Education Institutions, with the blackboard being the main tool for knowledge transmission, in which students transcribe the content into their notebooks. Over the years, a new approach of Problem-Based Learning (PBL) has emerged, characterized by the dichotomy between theoretical formation and professional practice, as studied by Ponciano, Gomes, & Morais, (2017).

The curriculum of the Production Engineering (EPR) course at the University of Brasília (UnB) integrates into its innovative structure the Problem-Based Learning (PBL) method, which encompasses seven Production Systems Projects (PSP) disciplines. These disciplines are distributed throughout the student's academic trajectory, starting in the fourth semester and ending in the penultimate period of the course. The purpose of PBL is to encourage students to apply theoretical concepts of Production Engineering to solve concrete problems that arises from external stakeholders, promoting an integrated understanding between the demands of professional practice and the various areas of knowledge, facilitating the understanding of the variety of determining factors involved in solving challenges (Monteiro, Reis, Silva, & Souza, 2017).

The practical issues faced by organizations, regardless of whether they are in the private or public sector, large or small, active in industry or the service sector, serve as the basis for the topics addressed in the PSP disciplines. The main challenge is to identify these external stakeholders. To facilitate this process, the initial module of the

Unified Active Methodology Platform (PUMA) was developed, whose outline is described in the study by Monteiro, Campos, Lima, & Melo, (2018). This module focuses on automating the submission process of project proposals for PSP disciplines originating from real challenges faced by external stakeholders.

The Unified Active Methodology Platform (PUMA) originates from the Teaching Program for the Third Millennium (A3M) of the Distance Education Center (CEAD) of UNB and has been in development since then with the support of different multidisciplinary teams (Monteiro, Lima, Mariano, & Júnior, 2020). The platform features functionalities that assist in the process of capturing projects to be executed by students in the PSP disciplines of the Production Engineering course at the University of Brasília.

This study aims to present the continuous evolution of the PUMA Platform, focusing on updating the functionalities and layouts implemented in its development process, and is organized into five others sections, namely: the second section provides a literature review, covering current and relevant research fronts on the topic; the third section describes the methodology employed in the research, containing the methods used and their structuring; the fourth section details the results of the first module of PUMA, the implemented functionalities and the risks associated with its development; the fifth section shows students' views on the PUMA projects and the learning process; conclusions are finally presented in the sixth section.

# 2 Background and Related Works

In this section, relevant concepts underpinning the proposal of this study, along with similar research conducted, are addressed through a robust literature review.

## 2.1 PBL Approach (connecting projects to students)

Problem-Based Learning (PBL) is an educational approach that prioritizes the use of real-world dilemmas to foster students' critical thinking development, promote problem-solving skills and facilitate the acquisition of knowledge about key concepts relevant to the area under analysis. These attributes contrast with traditional methods, which typically present a practical problem only after the exposition of theoretical content (de Andrade, dos Santos Jr. Pimentel, Bittencourt, & de Santana, 2010). Although originally developed for the medical course context, Problem-Based Learning (PBL) has been adopted in various fields, including engineering. Successful experiences in implementing PBL in Engineering programs are evidenced, for example, in the Production Engineering course at the University of Brasília, Brazil, and in the Computer Engineering course at Aalborg University, Denmark (Betemps, Cechinel, & da Nóbrega Tavares, 2008). The literature describes a series of activities aimed at guiding students in identifying solutions to the problem (Gallagher, 2023). In this context, the approach is described in which a challenge is presented to students who, organized in groups, collaborate to analyze, define, and solve the problem based on their existing knowledge. Through discussions, students identify and record learning issues related to aspects of the problem they do not fully understand. Subsequently, the issues are prioritized by the group, and a plan is devised to investigate them, including who will be responsible, how, and when they will be addressed for future sharing. Upon gathering again, students explore the issues raised earlier, integrating new knowledge acquired into the context of the problem. At the end of the process, students participate in individual and collective assessments to develop self-assessment skills and provide constructive feedback to peers.

## 2.2 Benefits of implementing the PBL methodology

The current educational process is at a stage of operational exhaustion; and the rapid obsolescence of the vast array of knowledge transmitted to students fuels this debate. There is a consensus that conventional approaches no longer foster theoretical and practical learning nor encourage the cultivation of other forms of knowledge considered relevant in the academic, professional, and social spheres. However, even in the face of accepting the limitations of traditional models, higher education institutions are immersed in a crucial discussion: how to promote skills and attitudes for continuous and independent lifelong learning while facing the responsibility of teaching an increasing array of technical-scientific knowledge without overloading curricula or prolonging formal education (Cerqueira, Guimarães, & Noronha, 2016).

Like any educational method, PBL, despite its potential, presents risks, advantages, and disadvantages. The advantages identified in this approach include facilitating the acquisition of knowledge in a more lasting and meaningful way, as well as the development of professional skills and attitudes by students. These benefits seem to be consistent regardless of the implementation context, its structure, educational level, and field of study. According to studies conducted by Fernandes, Mesquita, Flores, & Lima, (2014), PBL encourages collaboration among students, promoting more intense communication among them and favoring the establishment of bonds not only among peers but also with teachers over time. Additionally, in this environment, students tend to take a more proactive stance when faced with unknown topics, seeking support for project development, and develop the ability to meet deadlines set by tutors and group members, aspects that reflect patterns observed in professional life (Gomes, Brito, & Varela, 2016).

## 2.3 Multidisciplinarity in software development process

Over time, the evolution of software development practices has been evident. From the era of the waterfall model, characterized by sequential software construction, to contemporary agile methodologies, where software development is progressively iterative and incremental (Sommerville, 2011).

Current problem-solving approaches through Design Thinking (Panke, 2019) have been employed for requirement identification (Bernal, Raimondi, de Oliveira, Inoe, & Matsuda, 2018), providing significant contributions to development groups. The rapid development of minimum viable product prototypes (Caroli, 2015) to validate intermediate models together with agile software development methodologies (Schwaber, & Beedle, 2001) demands that professionals, predominantly from the computing field, demonstrate flexibility and multifunctional capability.

The article by Brauner, Janissek-Muniz, Granville, Moura, Fetter, & Nazar, (2017) describes the UFRGS 2016 App Challenge, an event with hackathon characteristics, organized with the purpose of integrating knowledge from students in Administration, Design, and Computing courses. The adopted methodology involved the formation of multidisciplinary teams, which faced the challenge of developing mobile applications over a weekend, covering prototyping, business modeling, and validation activities. The results show that multidisciplinary teams, adopting a product-centric approach, can contribute complementarity and collaboratively to application development.

The research conducted by Martins (2016) describes a successful multidisciplinary educational experience in a class of the fifth period of the Information Systems course at the Federal Institute of Goiás/Campus Luziânia. In this experience, students were engaged in software project development that integrated various disciplines in the same knowledge domain, offering a practical approach that served as a basis for future activities. This work required the application of knowledge from disciplines such as Web Programming, Database, Software Engineering, Design Patterns, Requirements Analysis, and Human-Computer Interface.

# 3 Methodology

This study is an applied and qualitative research focused on the Unified Platform for Active Methodologies (PUMA). A survey was conducted with students to assess the strengths and areas for improvement of the development process, as well as the learning experience. The project receives funding from Foundation of Research Support for the Federal District (FAP-DF), a research support foundation in the Federal District. The development team consists of 15 individuals, including 9 developers, 1 designer, 1 lead technician, 1 quality assurance specialist and 3 platform creators (product owners). Ten team members participated in the research, including 8 developers, 1 Scrum Master and 1 designer.

A survey was conducted through a form with 10 questions. For data collection, a 5-point Likert scale was used, that is, two extremes, two intermediates, and a neutral opinion. Therefore, from 1 (Poor or Does not contribute or Strongly disagree) to 5 (Excellent or Contributes significantly or Strongly agree). To analyze the answers, pie charts were created, which allow visualization of responses on the Likert scale. The questions were divided into five categories: 1) software development process, 2) agile rites used in the project, 3) clickup for task management, 4) learning process, and 5) team integration.

The research progressed through several stages. The first stage outlines the development process of the PUMA platform, while the second stage examines its current state. The final stage presents the results of the student survey.

# 4 Results

The process for developing the PUMA platform adopts a hybrid methodology, with Agile as its main method. This section presents the process of developing and shows the main screens of PUMA.

## 4.1 PUMA platform development process

The development process comprised ten steps followed by students and professors respectively from Software Engineering and Production Engineering at the University of Brasília (UnB), as illustrated in Figure 1, which delineates the workflow during the research.

In the discovery (Step 1), the Product Owners, Scrum Master, and UX/UI Designer focused on understanding the needs (Step 2), which served as inputs for creating prototypes (Step 3). Visual representations of interfaces were crucial for defining the requirements (Step 4), along with acceptance criteria and business rules. Subsequently, the development team participated in planning meetings (Step 5) to prioritize tasks and estimate the effort required for each functionality. During the development (step 6), functionalities were coded and tested (step 7) interactively to ensure they met the established requirements. Following this, all software components were accepted (Step 8) by platform creators (product owners) after a business valuation. The retrospective (Step 9), or retro, is a structured meeting for reviewing the work done and the development process, highlighting takeaways and action plans to improve results. Additionally, team members held daily stand-up meetings (Step 10) to discuss their progress, plans, and any obstacles they encountered.

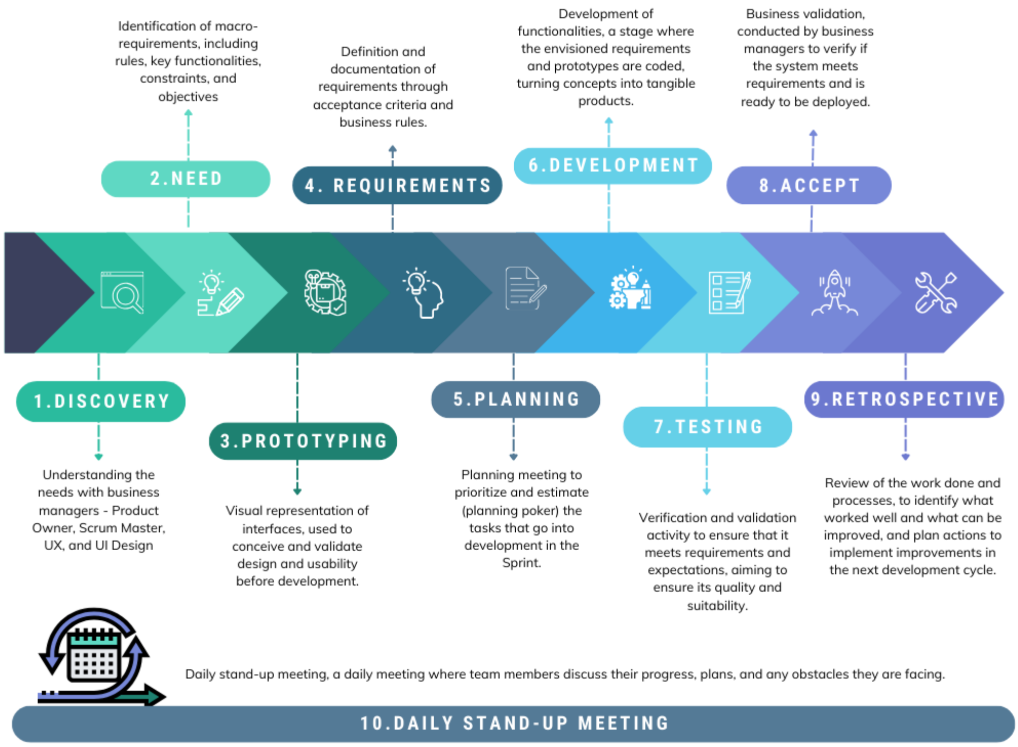



Figure 1. PUMA platform development process

## 4.2 Results of the screens developed in Epic 1

The figures two to eight depict the functionalities developed during the first epic.

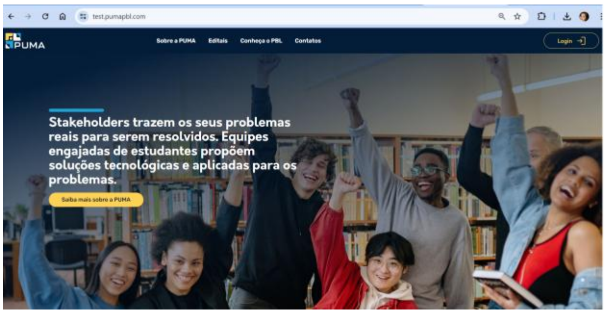
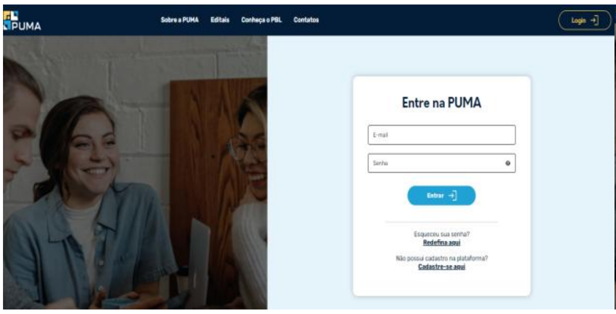




Figure 2.a Functionality "PUMA Home screen - general"  Figure 2.b Functionality "PUMA Home screen - public notice"

The Figures 2.a and 2.b show the homepage developed, the platform has four subsections, each one with a specific topic about the platform. They are: i) about the platform; ii) public notice; iii) learn more about PBL and iv) contacts.



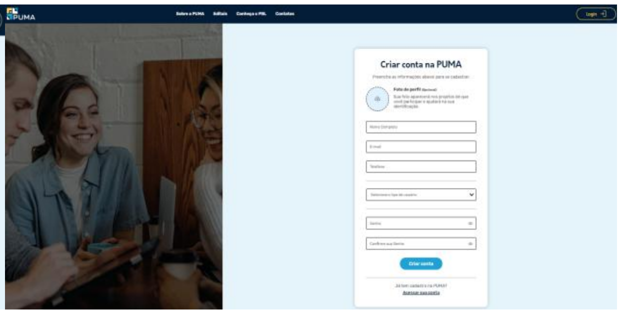




Figure 3.a Functionality "Login" screen  Figure 3.b Functionality " User Sign in "screen

The Figures 3.a and 3.b show the login page, where the user can recover your password or Sign in to the platform.

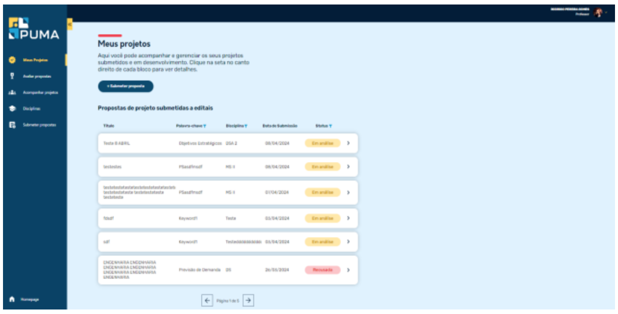



Figure 4. Functionality "My Projects" screen

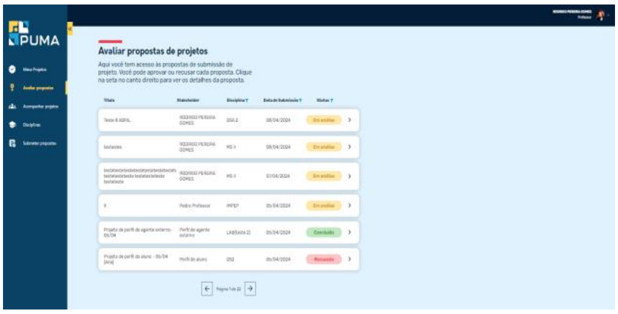



Figure 5. Functionality "Proposal Evaluation" screen

Figures 4 and 5 show the functionalities "My Projects" where the user can see the projects that were submitted or the ones being developed. "Proposal Evaluation" is a functionality where the professors can read and evaluate the project's proposals as accepted or denied.

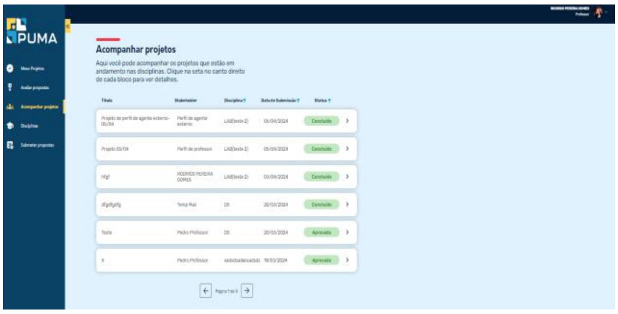



Figure 6. Functionality "Keep up with Projects "

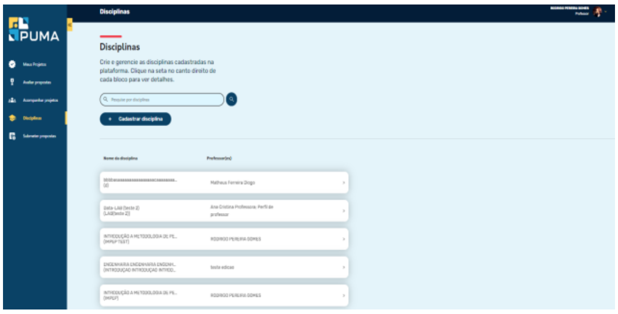



Figure 7. Functionality "Disciplines"

Figures 6 and 7 showcase the functionalities "Keep up with Projects" and "Disciplines." The first one focuses on keeping up with the projects. Once projects are accepted, they will be displayed on this screen, showing the discipline associated with the project and the professor who accepted it. The second figure illustrates the Disciplines functionality, where teachers can log in to courses and view disciplines offered by other teachers.

Figure 8 displays the "Project proposal submission", where the projects are submitted. Either by professors, students or external stakeholders.

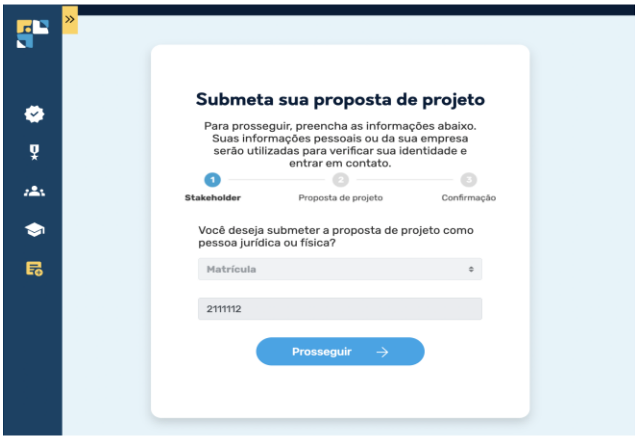



Figure 8. Functionality "Project proposal submission"

# 5 Students' view of the PUMA project and the learning process

The survey was carried out using a form that covered the following categories: software development process, agile rites used in the project, clickup for task management, learning process, team integration, positive points of the PUMA project and suggestions for improvements and additional comments, as shown in figures nine to twelve. Figure 9 illustrates students' perspectives on aspects of the software engineering process.

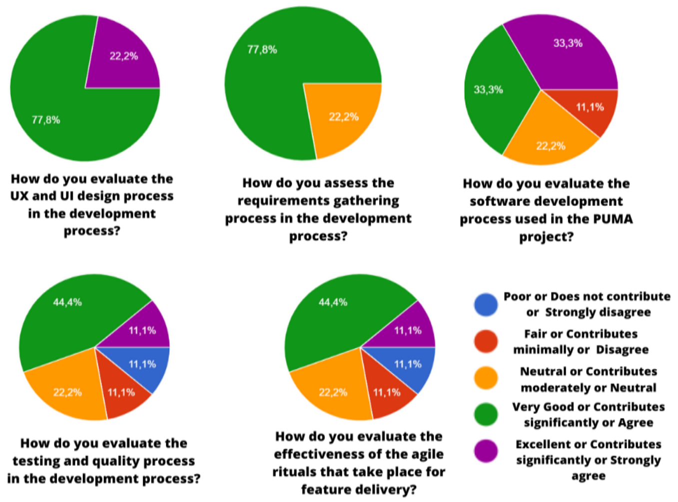



Figure 9. students' perspectives on aspects of the software engineering process.

The analysis of the survey reveals an overall positive picture in the development process of the PUMA project, with aspects such as User Experience/User Interface (UX/UI) design being well rated by the team. However, areas of opportunity were also identified, such as the requirements gathering process, software development, testing, and quality, where the team expressed different levels of satisfaction and perception. Figure 10 Illustrates the student's perspective on the aspects of rituals and tools.

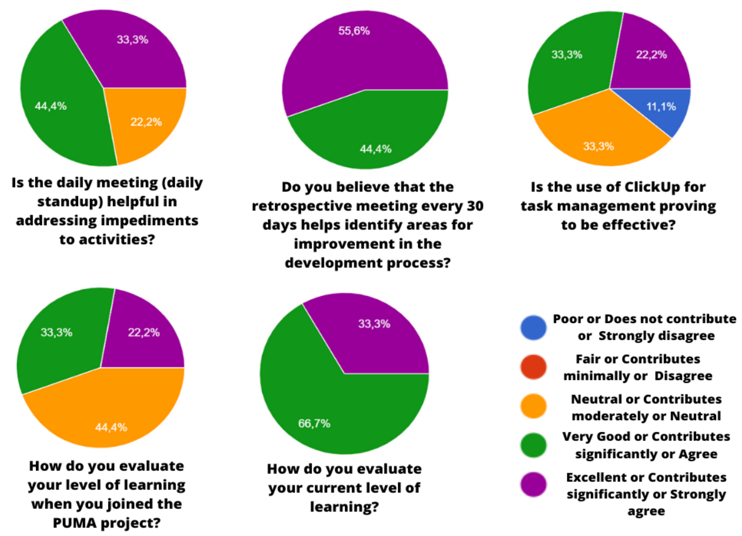



Figure 10. Illustrates the student's perspective on the aspects of rituals and tools.

Regarding agile practices and learning, the analysis reveals a predominantly positive scenario. Most participants rated the effectiveness of agile practices, the usefulness of the daily meeting, and the relevance of the retrospective meeting for identifying improvements positively. Additionally, the students expressed satisfaction with their learning level, both upon joining the project and currently. These results underscore the importance of continuous evaluation and improvement of processes to ensure the ongoing effectiveness and quality of the PUMA project. The figure 11, on the other hand, illustrates a word cloud from the development team's perspectives presenting the positive aspects of the PUMA project.


Figure 11. Word Cloud illustrating the positive aspects of the PUMA project succinctly.

The development team emphasized the positive aspect of team meshing and integration within the development process. According to the survey results, 55.6 percent of the students believe that integrating teams from various areas significantly contributes to the project's success, while 44.4 percent think it contributes greatly. It's crucial to underscore that skills from different areas are vital for a more resilient software development process, as evidenced by the survey findings. Figure 12 outlines a word cloud with students' recommendations to improve the development process.


Figure 12. Word Cloud depicting suggestions for enhancing the PUMA development process.

Students appreciate the development methodology but suggest greater involvement in the requirements gathering and prototyping process, currently managed solely by the Scrum Master and project designer. They also recommend enhancing backend tests and improving the organization of folder architecture and documentation for both front and back ends. Finally, the students express their belief that the development process has significantly contributed to their learning and skill enhancement.

The main survey results and lesions to be learned are: 1) Multidisciplinary teams promote a better workflow 2) PBL Methodology was essential on the teaching-learning process of the students 3) Good results from following the Agile Methodology, regarding amount of deliverables per cycle.

# 6 Conclusion

The goal of this study was achieved, that is, the recent results obtained in the PUMA development process were presented, highlighting the functionalities, along with their screens. Following agile practices, the complete development process consists of multiple cycles, rather than a single sequential process. This continuous process has been improved with each software development cycle.

Through the analysis of the survey answers about aspects of the software engineering process, agile rituals, and tools, students' points of view were identified, as well as positive aspects and suggestions. This data is important for enhancing PUMA development and the learning process.

This paper only focused on the results of Epic 1, which were prioritized through agile practices used to organize the development. Thus, other modules are also future work to be developed such as Team Building, Peer Assessment, Stakeholder Feedback, Assignment of Course Grades, Evaluation of the PBL methodology, and Alumni Follow-up.

Adoption of the functionalities outlined in this paper could be an opportunity to improve the number of real-world problems offered to students by stakeholders, and to support processes such as "Proposal Evaluation" and "Keep up with Projects", which are crucial for applying the PBL methodology.

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# Tailoring Portfolio, Program, and Project Management to a Complex System

Gabriel de Lanna Fiuza Curi Garcia[1], Simone Borges Simão Monteiro[1], Dianne Magalhães Viana[2], Jens Myrup Pedersen[3]

[1] Production Engineering Dept., Faculty of Technology, University of Brasília, Brasília, Brazil
[2] Mechanical Engineering Dept., Faculty of Technology, University of Brasília, Brasília, Brazil
[3] Aalborg University, Denmark

Email: gabriel.lanna@aluno.unb.br, simoneborges@unb.br, diannemv@unb.br, jens@es.aau.dk

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**Abstract**

Managing a complex portfolio of projects requires a mature structure that considers portfolio, program, and project management standards and best practices tailored to the specific system. This paper provides a framework for the development and implementation of a management model for a complex portfolio – the Erasmus+ initiative called *Egalitarian*. The research has an applied nature and utilizes an action research strategy with a qualitative approach. Based on a bibliographic review and observation, the paper analyses the portfolio management structure of the *Global Students SDG Challenge* and tailors a framework for an updated management model.

**Keywords**: Portfolio Management; Program Management; Project Management; Complex System; Tailoring; Framework.

# 1 Introduction

To prepare an engineering student for the job market, universities must develop not only technical skills but also transversal skills such as teamwork, leadership, communication, adaptability, and project management (Monteiro *et al.*, 2012). Problem-Based Learning (PBL) and Project-Based Learning (PjBL) are a good way for students to work in interdisciplinary teams and on real-world problems, achieving the competencies mentioned above (Pedersen *et al.*, 2020).

Initiatives that promote international and interdisciplinary student projects bring another level of cooperation, insights, and complexity, requiring a careful project design to ensure that the students can collaborate and yet fulfill the requirements and learning objectives of their home universities (Pedersen *et al.*, 2020). The *Global Students SDG Challenge* and now *Egalitarian* are two of these initiatives. *Egalitarian* is an Erasmus+ initiative co-funded by the European Union, and it has more than 25 teams working on approximately 8 programs each semester, involving students from Brazilian and European universities. Managing such a complex portfolio of projects requires a mature structure that considers portfolio, program, and project management standards and best practices.

This article's main objective is to provide a guide for the development and implementation of a management model for a complex portfolio. Its specific objectives are (i) to understand the current portfolio, program, and project management standards and best practices, (ii) to describe the model used for managing the *Global Students SDG Challenge* portfolio, and (iii) to propose a tailored framework for developing a new management model for the *Egalitarian* portfolio.

The paper is organized as follows. First, a theoretical background is presented, to give context and relevant information about the current best practices. After this, the research methodology is explained, followed by the results achieved from past research and a discussion based on the authors' experience with the *Global Students SDG Challenge* portfolio, and at last the conclusion.

# 2 Theoretical Background

This section introduces theoretical concepts that underpin the research.

## 2.1 Portfolio, Program, and Project Management

A portfolio consists of a collection of projects, programs, subsidiary portfolios, and related operations managed in an integrated way to achieve an organization's strategic objectives. A program includes related projects, subsidiary programs, and program activities managed in a coordinated manner to obtain benefits not available from managing them individually. Programs and individual projects with strategic importance are part of a portfolio – even if they are not directly related or interdependent – if they are linked to the organization's strategic plan through the portfolio. (PMI, 2017a)

Portfolio management focuses on ensuring the portfolio is performing consistently with the organization's objectives and evaluating portfolio components to optimize resource allocation, and program management applies knowledge, skills, and principles to a program to achieve the program objectives and obtain benefits and control not available by managing related program components individually (PMI, 2023). Project management is the application of knowledge, skills, tools, and techniques to project activities to meet project requirements and deliver the intended outcomes (PMI, 2021).

Portfolio, program, and project management are based on principles and performance domains, such as: Obtain and maintain the sponsorship and engagement of senior management and key stakeholders; Navigate complexity to enable successful outcomes; Create a collaborative project team environment; Tailor based on context. (PMI, 2017a; 2021)

A major reason for project failure is the lack of benefits management (Walenta, 2016). Benefits management is not a knowledge area covered by project management, but by program management (PMI, 2017b). Large organizations and organizations that want to achieve higher levels of project management maturity need to separate program and project management, since project management standards focus on the traditional triangle of scope/quality, time, and cost, while the triangle for program management could be defined as strategy/benefits, governance, and stakeholders (Walenta, 2016).

Project management is also important in education contexts. Fernandes, Dinis-Carvalho and Ferreira-Oliveira (2021) studied the application of Scrum to complex Project-Based Learning environments and found that task assignment, performance monitoring, visual management, and regular feedback were considered the main advantages of using Scrum in PjBL teams, which had a positive impact on student performance.

## 2.2 Portfolio, Program, and Project Management Offices (PMOs)

An important role in portfolio, program, and project management is the PMO. At the portfolio level, a PMO is an organizational entity that provides various capabilities and processes supporting portfolio management (PMI, 2017a). A program management office standardizes the program-related governance processes and facilitates the sharing of resources, methodologies, tools, and techniques. It may be specific to an individual program, or support multiple organization's programs (PMI, 2017b). A project management office has a similar function to the program management office but at the project level. The projects supported or administered by the project management office may not be related other than by being managed together (PMI, 2023). The main activities and responsibilities for each type of PMO – Portfolio, Program, and Project Management Offices – can be found at Project Management Institute (2017a; 2017b; 2023).

The specific form, function, and structure of a PMO are dependent upon the needs of the organization that it supports. There are three main types of PMOs in organizations, varying the degree of control and influence it has on projects within the organization (PMI, 2023):

- **Supportive:** Supportive PMOs provide a consultative role to projects by supplying templates, best practices, training, access to information, and lessons learned from other projects. This type of PMO serves as a project repository. The degree of control provided by the PMO is low.
- **Controlling:** Controlling PMOs provide support and require compliance through various means. The degree of control provided by the PMO is moderate. Compliance may involve:
    - Adoption of project management frameworks or methodologies;
    - Use of specific templates, forms, and tools; and
    - Conformance to governance frameworks.
- **Directive:** Directive PMOs take control of the projects by directly managing the projects. Project managers are assigned by and report to the PMO. The degree of control provided by the PMO is high.

In the academic research environment, a PMO may also be useful. Widforss and Rosqvist (2015) analyze the PMO of a Swedish university, which provides professional project management services to researchers and research projects. The survey conducted shows that structure, tools, and templates are less useful for complex projects than governance, management support, experience, and skill. Fernandes, Souza, Tereso and O'Sullivan (2021) present three PMO structures for University Research Centres (URCs) with a total of twenty-six functions. These are divided into the three PMO typologies, with an evolution logic: 'basic' PMO, 'intermediate' PMO, and 'advanced' PMO. Functions go from general guidelines and definitions to strategic influence and direct management of the R&D projects.

## 2.3 Complex Systems and Systems Thinking

The inherent complexity of portfolio management often results in a context characterized by overlapping and potentially conflicting stakeholder interests. This complex landscape presents portfolio managers with the challenge of effectively navigating a high flow of unfiltered information while simultaneously experiencing not enough relevant communication (PMI, 2017a). Other components that influence portfolio and project complexity include, but are not limited to: number of unpredictable stakeholders who need individual care; dimension of change imposed on the environment; complicatedness or unpredictability of project results; timeline and number of parallel activities; organizational structure; geographic distribution (*Svenskt projektforum*, 2011, as cited in Widforss & Rosqvist, 2015).

A systems thinking approach tends to help analyze the portfolio system as a whole (PMI, 2017a), and understand how the portfolio system and subsystems fit into the larger context of the organization and day-to-day life (International Council on Systems Engineering, 2006).

The portfolio may be analyzed and managed as a System-of-Systems, i.e., as "an interoperating collection of component systems that produce results unachievable by the individual systems alone" (International Council on Systems Engineering, 2006), which helps portfolio managers to analyze the whole portfolio and focus on the effects of the interactions between the portfolio components. Employing a systems perspective facilitates a more comprehensive understanding of both the objectives driving change initiatives and the mechanisms employed to achieve them. This approach also provides valuable insights into the individual components of the portfolio and their interactions within the broader organizational system (PMI, 2017a).

## 2.4 Tailoring

Project Management Institute (2021) defines tailoring as "the deliberate adaptation of the project management approach, governance, and processes to make them more suitable for the given environment and the work at hand". Project aspects that can be tailored include life cycle and development approach selection, processes, engagement, tools, and methods and artifacts. The process of tailoring for the organization and for a specific project is composed of four steps (PMI, 2021):

- **Select Initial Development Approach:** Choose a development approach best suited for the endeavor;

- **Tailor for Organization:** Modify based on organizational modifications;
- **Tailor for Project:** Adjust based on size, criticality, and other factors;
- **Implement Ongoing Improvement:** Inspect and adapt.

According to Project Management Institute (2023), "tailoring is necessary because each project is unique". The standards for portfolio, program, and project management identify several processes, tools, techniques, inputs, and outputs, but not everything is required for every project or group of projects. The importance of each constraint and performance domain is different for each project, program, or portfolio, and the management of these elements should be tailored based on the environment, organizational culture, stakeholder needs, and other variables (PMI, 2023).

Additional guidelines for tailoring, based on the Agile Practice Guide (PMI, 2017c), include: Restructure large projects as multiple smaller projects; Break large teams into multiple smaller teams and use program management to synchronize and coordinate; Use agile and lean program management to organize the larger effort; Use tools like instant messaging, video conferencing, and electronic team boards to help bridge communication gaps; Consider building centers of competencies to help provide guidance and build domain knowledge, especially when team members are inexperienced.

# 3 Methodology

This research has an applied nature and utilizes an action research strategy with a qualitative approach. A highly interactive method, action research is often used in educational settings, and it aims to simultaneously investigate and solve an issue (George, 2023). One of the characteristics of this method is the active role of the researcher as a true agent of intervention and change in organizations (Westbrook, 1995, as cited in Ganga, 2011).

This research has two steps. Step 1 focuses on presenting the portfolio, program, and project management model used by the production engineering undergraduate program at the University of Brasília. It complements the works made by Barreto (2022) and Brito (2023), and it uses both bibliographic analysis and observation techniques. Step 2 aims to suggest a framework for developing a new model for the portfolio, program, and project management of the international Erasmus+ program called *Egalitarian*. The framework consists of a tailoring of the portfolio, program and project management approach, governance, and processes. A literature review provided theoretical background for both steps.

# 4 Results and Discussions

## 4.1 Old Model

The production engineering course at the University of Brasília has a set of subjects with the proposal to apply the active learning methodology through projects that have scopes related to other technical subjects in the student's curriculum (Barreto, 2022). Some of these project-based subjects are integrated and were part of a portfolio of projects arising from the *Global Students SDG Challenge*, a student-centered initiative that connects students from different universities and countries to develop solutions that help achieve the 2030 Agenda's goals.

The portfolio involved courses and subjects from the University of Brasília, Brazil, and Aalborg University, Denmark. The PSP2 and PSP5 subjects were fixed subjects in the portfolio, and other subjects were involved depending on the projects being developed in a specific semester.

The Portfolio Board was made up of key professors and students that coordinated the PMO. Their main responsibility was to define the portfolio components, according to the *Global Students SDG Challenge* strategy and objectives. The PMO served many functions, such as (Brito, 2023):

- Strategic management and transformation, team and human resources management, and portfolio management, performed by professors in the Management role;
- Strategic management and guidance regarding the PMO, team and human resources management, and learning and knowledge management, performed by students in the Coordination role;
- Projects and programs monitoring, performed by students in the Control role; and
- Management of information tools and systems, management of data intelligence and communication, and management of processes and improvements, performed by students in the Support role.

Teams were integrated in a matrix way: students of the same subject interact and share lessons learned, and students of the same theme cooperate and work together to deliver their scopes. Same-subject interaction is encouraged by the subject professors, and same-theme synergy is influenced by the Control team of the PMO.

Projects inside the *Global Students SDG Challenge* portfolio used a hybrid project management approach that combined iteration-based agile approaches with predictive life cycle elements (PMI, 2017c). The project execution was divided into sprints, and the project deliverables were organized in backlogs with epics, user stories, and tasks. All tasks must have a Definition of Done (i.e., an acceptance criteria).

The PMO provided for each team the project context, general scope, and main deliveries from last semesters. At the beginning of the project executions, all teams should provide a filled Project Model Canvas (Finocchio Júnior, 2013) and an initial product backlog, based on the directions provided. For each sprint, the team must detail a sprint backlog and provide a status report for the PMO. These artifacts and information feed a dashboard from the PMO, used for monitoring the portfolio.

This model, that was used to manage the *Global Students SDG Challenge* portfolio, was updated each semester, based on lessons learned, results achieved, the portfolio's strategic objectives, and portfolio, program, and project management best practices. For the next three years, the *Global Students SDG Challenge* was replaced by *Egalitarian*, an Erasmus+ program that will involve not only the University of Brasília (Brazil) and Aalborg University (Denmark) but also the University of Minho (Portugal) and Saxion University (Netherlands). Therefore, the portfolio became more complex – with more stakeholders, professors, teams, and projects –, which requires a more robust management and control system, e. g., with key performance indicators being monitored (at a project and a portfolio levels). The framework proposed on the next topic aims to guide the development of a new model for the portfolio, program, and project management of the *Egalitarian* portfolio.

## 4.2 Proposed Framework

Based on (i) the portfolio, program and project management principles, performance domains, processes, tools, methods, and artifacts, (ii) the model used for managing the *Global Students SDG Challenge* portfolio, and (iii) the processes and guidelines for tailoring, this section details the proposed framework for managing the new *Egalitarian* portfolio. The framework focuses on the adjustments needed in the old model; elements presented in the last topic that aren't updated or altered in this topic remain under use.

Figure 1 shows the new portfolio structure. The subsidiary portfolios, one for each country/university, are composed of programs and projects that may be integrated into other programs and projects inside the other subsidiary portfolios. Teams from different universities should work together to deliver their projects in an integrated way, and the PMOs are responsible for facilitating that cooperation. The number and scope of programs and projects can vary for each semester.

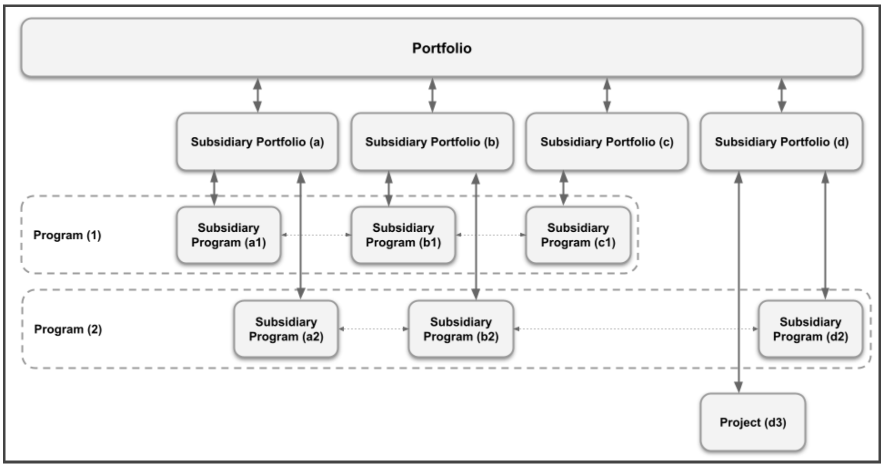


Figure 1. New Portfolio Structure

Figure 2 shows the new portfolio management structure. The Portfolio Board members are the professors in the Management role inside the PMOs and the students in the Coordination role of the Main PMO. Other students and professors may be involved in the Portfolio Board if needed. Each PMO – here considered a Portfolio, Program, and Project Management Office – is responsible for managing a subsidiary portfolio. The Main PMO manages both its subsidiary portfolio and the Auxiliary PMOs. Each Team is responsible for executing a project, and it may have one of the two following structures: a Product Owner (PO), a Scrum Master (SM), and an Executing Team; or a Project Manager (PM) and an Executing Team. The structure adopted will depend on the Team's subject and university.

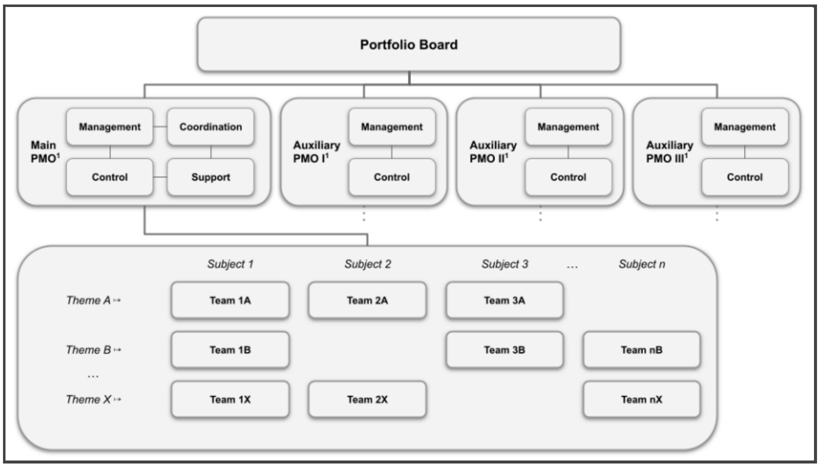


Figure 2. New Portfolio Management Structure. ([1]adapted from Brito, 2023)

The Portfolio Board functions and responsibilities are: Define the portfolio strategy, objectives, and guidelines; Define the portfolio components and general project themes for each semester; Establish partnership guidelines; Develop the portfolio charter; Develop the portfolio roadmap; Manage the portfolio value. (adapted from Barreto, 2022 and PMI, 2017a)

Table 1 describes the Main PMO functions and responsibilities. Table 2 details the Auxiliary PMOs functions and responsibilities.

Table 1. Main PMO Functions and Responsibilities.

| Role | Functions and Responsibilities |
|---|---|
| **Management** | **Strategic management and transformation:** Manage resource allocation within the PMOs and the portfolio; Assist in the implementation of frameworks and methodologies for managing the portfolio, PMOs, subsidiary portfolios, and programs; Implement organizational changes and transformations in the PMOs.<br>**Team and human resources management:** Define the expected profile of students for each PMO role; Select the PMO team.<br>**Portfolio management:** Manage the portfolio; Monitor the portfolio performance. |
| **Coordination** | **Strategic management and guidance regarding the PMOs:** Guide resource allocation within the PMOs; Provide frameworks and methodologies for managing the portfolio, PMOs, subsidiary portfolios, and programs; Guide the need to implement organizational changes and transformations in the PMOs; Coordinate communication across portfolio components.<br>**Team and human resources management:** Guide the expected profile of students for each PMO role; Execute the integration process for new PMO members; Develop and conduct training and mentoring of human resources in portfolio and program management skills, tools, and techniques; Monitor and advise Support and Control teams and Auxiliary PMOs.<br>**Learning and knowledge management:** Manage the PMOs lessons learned meetings; Manage PMOs knowledge base; Train PMOs members. |
| **Control** | **Portfolio and program monitoring:** Monitor the subsidiary portfolio performance; Monitor the programs and subsidiary programs performance; Conduct project audit; Manage interfaces with project customers and project sponsors; Monitor projects and programs risks; Ensure the production of project reports by the Teams. |
| **Support** | **Management of information tools and systems:** Provide tools and information systems for project management, PMOs knowledge management, and portfolio metrics and KPIs management; Manage project documentation database; Provide training and support on the use of tools for PMOs members.<br>**Management of data intelligence and communication:** Prepare periodic reports containing relevant insights into data acquired through tools and information systems used for project management.<br>**Management of processes and improvements:** Carry out fault diagnosis in internal processes and identify improvement needs within the PMOs. |

(adapted from Barreto, 2022, Brito, 2023 and PMI, 2017a)

Teams functions and responsibilities may have two structures. In the first one, a Project Manager (PM) is responsible for managing project stakeholders, improving problem definition and project scope, providing project reports to the PMO, and managing project risks, while the Execution Team proactively study and seek possible solutions for the project, organize the deliveries for each milestone of the project timeline, and execute the project. In the second model, a Scrum Master (SM) lead, train, and guide the Team in adopting Scrum, help project members and stakeholders understand and apply an empirical approach to complex work, and remove barriers between stakeholders and the Team; a Product Owner (PO) develop and explicitly communicate the Product Goal, create and communicate Product Backlog items, prioritize Product Backlog items, and ensure the Product Backlog is transparent, visible, and understandable; and the Execution Team create a plan for the sprint – the Sprint Backlog –, gradually introduce quality by adhering to a Definition of Done, adapt the plan each day toward the Sprint Goal, and provide a status report for each sprint. (adapted from Barreto, 2022 and Schwaber & Sutherland, 2020)

Table 2. Auxiliary PMOs Functions and Responsibilities.

| Role | Functions and Responsibilities |
|---|---|
| **Management** | **Strategic management and transformation:** Manage resource allocation within the Auxiliary PMO and the subsidiary portfolio; Assist in the implementation of frameworks and methodologies for managing the Auxiliary PMO, subsidiary portfolios, and subsidiary programs; Implement organizational changes and transformations in the Auxiliary PMO. **Team and human resources management:** Select the Auxiliary PMO team. **Subsidiary portfolio management:** Manage the subsidiary portfolio; Monitor the subsidiary portfolio performance. |
| **Control** | **Subsidiary portfolio and subsidiary program monitoring:** Monitor the subsidiary portfolio performance; Monitor the subsidiary programs performance; Conduct project audit; Manage interfaces with project customers and project sponsors; Monitor projects and subsidiary programs risks; Ensure the production of project reports by the Teams. |

(adapted from Barreto, 2022, Brito, 2023 and PMI, 2017a)

The Main PMO serves as a Center of Excellence for the Auxiliary PMOs and the whole portfolio (PMI, 2017a). The number of professors and students in each role will depend on the capacity and capability analysis of each university, but ideally, a student in the Control role should be responsible for managing no more than 2 programs or subsidiary programs. On a project management level, the PMOs (specifically, the Control role) provide integration between teams, project scope, project management methodology, insights and mentoring, and project evaluation and feedback; the Teams provide status report, executive summary, difficulties and blockings, project deliveries, and ideas and feedback.

A framework is "a loose but incomplete structure which leaves room for other practices and tools to be included but provides much of the process required" (Think Insights, 2020). Therefore, the framework proposed in this section should serve as a guideline for the development of a new model for the portfolio, program, and project management of the *Egalitarian* portfolio. Additional tailoring may be necessary during the new model creation/implementation. Also, members from all 4 universities should be included in the next steps, to make sure that the final model fits all necessities and realities.

# 5 Conclusion

This paper contributes to the portfolio, program, and project management of an international Erasmus+ initiative that connects students and promotes interdisciplinary student projects, which impacts the students' personal and professional development. It provides a guide for the development and implementation of a management model for a complex portfolio by analyzing the current standards and best practices and the model used for managing the *Global Students SDG Challenge* portfolio. The tailored framework proposed provides a new portfolio structure with defined roles and responsibilities.

Future research may explore similar frameworks for different systems and organizations or focus on the creation and implementation of the complete *Egalitarian* portfolio management model based on the proposed framework. A further analysis of the framework impact on teaching and learning, from both the professors and the students' perspectives, is also welcomed.

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# Active Learning and Cybersecurity Training: Best practices and recommendations on using Cyber Ranges

Rasmi-Vlad Mahmoud[1], Marios Anagnostopoulos[1], Jens Myrup Pedersen[1]

[1] Cyber Security Group, CMI Section, Department of Electronic Systems, Aalborg University, Copenhagen

Email: rvm@es.aau.dk, mariosa@es.aau.dk, jens@es.aau.dk

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**Abstract**

Cybersecurity education commences at the high school level through gamified formats, seminars, or practical exercises. This educational trajectory extends to universities and corporate settings where the motivation varies. Cybersecurity training is facilitated by active learning and its dynamic approach which immerses learners in practical experiences, fostering adaptability in a rapidly evolving field. Suitable technologies for such approach are cyber ranges, these virtual environments mimic real-world IT infrastructure, providing a dynamic arena to face realistic cybersecurity scenarios, being defensive, offensive, or in tandem, within a secure environment. However, despite the evolution of the cyber range technologies in terms of technological and learning capabilities, there remain room for enhancing their integration into classroom activities. Our research endeavours to explore the integration of cyber ranges into pedagogical approaches by exploring existing literature and building upon Kolb's experiential learning framework. Specifically, emphasising the iterative nature of learning, this study situates the process within the realms of preparation, execution, and reflection on a cyber range. Lastly, it maps the learning outcomes with the ENISA's European Cybersecurity Skills Framework (ECSF) to facilitate the linkage between cybersecurity training and market's requirements. Our aim is to provide educators with a thought process to make informed decisions regarding the integration of a cyber range into their educational curricula. This entails reflecting on the diverse needs of target audiences, considering prior knowledge, and aligning instructional goals with desired outcomes.

**Keywords**: Cyber range; ENISA ECSF; Cybersecurity Education, Active Learning.

## 1 Introduction

The evolving global landscape necessitates a paradigm shift in engineering education to align with prevailing socio-economic and environmental trajectories. Vodovozov et al. (2021) underscore the pressing essential for cultivating a novel type of Engineer, denoted as a "T-shaped engineer", who exhibits not only deep domain expertise, represented by the vertical stem of the "T," but also adeptness in communication and collaboration within multidisciplinary frameworks, embodied by the horizontal crossbar of the "T". Consequently, businesses are increasingly adopting efficient methods to enhance workforce skills while professionals are urged to develop proficiency in technical, methodological, social, and personal competencies. (Vodovozov et al., 2021). Furthermore, Wolf et al. (2020) accentuate the significance of soft skills for prospective STEM practitioners, underscoring their parity with technical acumen in shaping the future workforce landscape. Recent studies indicate that practical training in real-life settings leads to superior outcomes compared to traditional lecture-based approaches (Vodovozov et al., 2021). This transition fosters a deeper understanding of theory and its practical applications, enabling students to articulate, implement, and evaluate ideas more comprehensively—an approach encouraged by active learning initiatives (Vodovozov et al., 2021).

Active learning is a form of instructional approach focused on student-driven activities guided by an instructor. Active learning stimulates student's interest and responsibility in creating their own knowledge by concrete experience. The teacher is the facilitator that converts the learning into an exciting and meaningful process, with the goal of bringing students into problem-solving situations that require collaborative efforts. As a result, active learning has gained significant traction in higher engineering education, with its efficacy demonstrated across the broader educational landscape (Vodovozov et al., 2021).

In this direction, cybersecurity learning is essential to improve. Cybersecurity vulnerabilities and their increased risks emphasize the need for cybersecurity professionals and their continuing education. This is why cybersecurity has evolved from a technology-only field to a domain where humans are considered an integral part of the security systems. However, this capacity is closely related to the users' sufficient skills and specialisation (Glas et al., 2023). Moreover, cybersecurity training is becoming necessary and relevant to the whole spectrum of users, not solely to the computer experts. The demand for training technical skills to operate diverse security mechanisms and increase awareness among non-technical users is constantly increasing (Glas et al., 2023). In this respect, cyber ranges are specialised virtual arenas that provide users with an environment tailored for learning cybersecurity techniques through practical exercises. While different approaches exist for building cyber ranges, the most straightforward is to consider a cyber range as a virtual emulation of a company's IT system. This way, it can mimic a real-world IT environment and facilitate offensive and defensive cybersecurity exercises within a controlled yet realistic environment.

Our work aims to investigate the cyber ranges' suitability for classroom teaching and examine how such technologies can be integrated into educational settings where learners' backgrounds, prior skills and expectations may differ. Overall, our contribution is to establish a comprehensive framework for tertiary educational institutions to incorporate cyber ranges into their curriculum by deploying these platforms as practical tools for training and education. While existing literature (Darwish et al., 2020), (Beauchamp et al., 2023) explores the educational aspects of cyber ranges, they usually focus on specific instances or offer conceptual perspectives through structured interviews. On the contrary, our study endeavours to consolidate the available literature and understand optimal approaches for the integration of cyber ranges into high schools and universities.

The paper is organised as follows: Section 2 discusses past initiatives around cybersecurity education and cyber ranges, and Section 3 explains our methodology. Furthermore, section 4 presents the information from the articles, while section 5 draws the author's recommendations towards cyber ranges. Finally, the paper concludes with Section 6.

## 2 Background

Cybersecurity education relies on environments that enable learners to actively practise technical skills, collaborate towards common objectives, and experiment in scenarios closely mirroring real-world situations, all without risking disruption to the operational systems (Glas et al., 2023). Despite their military origins, numerous organisations have embraced the concept and undertaken initiatives to construct and utilise cyber ranges across various use cases (Glas et al., 2023). This adoption stems from their effectiveness in delivering a secure and immersive environment for cybersecurity education, training, and testing (Glas et al., 2023). Moreover, educational institutions turn to those technologies to provide their students with environments that support their educational programs and train them in the cybersecurity skills required by the job market. Although these technologies continuously evolve, their suitability for in-class training and how they can successfully be integrated into curriculums is still to be determined.

Toward this direction, Darwish et al. (2020) aim to understand the utilisation of Cyber Ranges in educational institutions, providing insights into their uses, benefits, costs, and implementation methods, taking as a case study the Virginia Cyber Range. The authors recognise that Cyber Ranges significantly enhance cybersecurity education and student readiness, often without imposing significant financial burdens on the institutions. Despite some challenges, such as initial costs and staffing, the benefits of using Cyber Ranges for education outweigh these obstacles. Thus, they endorse collaboration with industry partners and other institutions to make them accessible to a broader audience. Similarly, Beauchamp et al. (2023) investigate how educators could incorporate the Virginia Cyber Range into cybersecurity education. Their analysis provides valuable insights into educators' perspectives, showing how cyber range resources support the progression of cybersecurity education. Additionally, their research underscores the benefits of employing cyber ranges for education, offering a secure and easily accessible virtual environment for applying classroom theories, participating in practicals, and facilitating opportunities for feedback and assessment. However, the authors acknowledge that the educators faced challenges in employing the cyber ranges and their features to their full potential despite the presence of informative video materials (Beauchamp et al., 2023). Moreover, they highlight several vital factors essential for effectively integrating cyber ranges into educational settings. These include the fact that successful integration is closely related to the stakeholders developing the comprehensive curricula, the instructor guides, and content aligned with cybersecurity learning objectives.

Even though the research by Darwish et al. (2020) and Beauchamp et al. (2023) focuses on a specific cyber range as a case study, they highlight the advantages of integrating the Virginia Cyber Range into teaching due to its cloud architecture and easy plug-in format. They also emphasise the necessity to acquire a deeper understanding of how these tools are employed for training/education, taking into account the experience levels of both educators and learners, situational factors, and the need for further research in these areas.

Kolb (1984) introduced the concept of experiential learning, defining it as a process that integrates experience, cognition, and behaviour, viewing learning as an ongoing process based on experience (Akella, 2010). Experiential learning diverges from behavioural learning by prioritising experience as the central and integral element. As Kolb's model describes the learning process, it highlights reflection and experience as essential learning mechanisms, suggesting that "learning from experience truly means learning from reflection and experience" (Akella, 2010). Furthermore, the research covering the past two decades showcases an expanding application of experiential learning across various disciplines, including psychology, medicine, nursing, accounting, education, and information science (Morris, 2020).

Kolb's four elements model describes the learning cycle, demonstrating how experience can be transformed by reflection of the concepts. As Kolb suggests the learners can enter at any stage and progress through the cycle several times, however, it is essential to pass through all the stages. In a nutshell, the entire learning process can be considered as the four key elements: "plan, act, observe, and reflect'' (Akella, 2010). These four stages can be summarised as follows:

- **Concrete experience (CE):** The initial stage forms the foundation of the learning process. When faced with a situation or problem, the learners acquire knowledge through adaptability and an open-minded approach rather than adhering to a systematic methodology.
- **Reflective observation (RO):** During this phase, the learners derive insights from their experiences by examining why and how they occurred. They reflect, observe, and critically analyse their experiences from various angles.
- **Abstract conceptualization (AC):** This stage involves relating the observations and reflections from the previous stage to established theories or subjective concepts. Students utilise logic and conceptual frameworks rather than relying solely on emotional responses to comprehend situations and issues.
- **Active experimentation (AE):** In the last stage, students apply theories to formulate predictions about real-world scenarios and subsequently act upon those predictions.

Kolb's framework emphasises the importance of experience in the learning process, aligning well with the practical nature of cybersecurity education. Since cyber ranges provide hands-on learning experiences, Kolb's model can help to assess how effectively such experiences contribute to knowledge acquisition and skill development. Moreover, Kolb's model incorporates reflection as a crucial element of the learning process. This is particularly relevant in cybersecurity education, where the learners need to critically evaluate their experiences to understand the implications of their actions and decisions. By applying Kolb's framework, the educators can assess whether cyber ranges facilitate meaningful reflection among students.

# 3 Methodology

Our study consists of five sequential steps designed to structure an assessment process to determine the suitability of cyber range technologies for specific use cases and their integration into educational activities. Additionally, the study evaluates their applicability across various contexts by examining existing approaches to cybersecurity education.

Figure 1. Overview of the methodology steps

The first step involves a Literature Search conducted between December 2023 and February 2024, using SpringerLink, ACM Digital Library, IEEExplore, and ScienceDirect. The search employed keywords such as "(Cyber range) OR (Cyber-range)" AND education; "(Cyber range) OR (Cyber-range)" AND learning; "(Cyber range) OR (Cyber-range)" AND curriculum, yielding an initial set of 170 articles published between 2016-2024. Subsequently, in Step 2, an initial screening process was conducted by reviewing the articles' titles and keywords to ascertain their focus on cyber ranges, resulting in a set of 76 relevant articles.

Step 3 was designed to provide a more comprehensive overview of the selected papers. This involved a thorough examination of each article, guided by a binary assessment framework consisting of two control questions:

1. Does the paper address educational aspects?
2. Is the cyber range developed by a research institution, particularly a university? Thus, this reflects the particular interest in cyber ranges used in the context of educational systems.

Articles failing to meet both criteria were excluded from further consideration. After completing step 3, the number of articles was 56. Since the timeframe to analyse and describe all of them will require a greater period, the authors decided to discuss the articles in a group setting to understand their applicability for this research. After abstract, introduction, contribution and conclusion was read 10 articles were selected that reflect the usage of cyber range in an educational setting.

Step 4 involves extracting critical insights from the selected articles, focusing on technical and personal competencies, learning format, target audience, skill equality, and facilitator. Since, cybersecurity professionals combine many competencies beyond technical skills, given the collaborative nature of the domain, we utilised the European Cybersecurity Skills Framework (ECSF) created by the European Union Agency for Cybersecurity (ENISA, 2022) to approach such analysis in a structured way.

Following, the learning format provided by the cyber ranges is examined based on Kolb's learning cycles. Specifically, we wish to examine how the cyclicity of the framework is reflected in the training to determine whether the participants are allowed adequate time and space for planning, having an authentic experience, reflecting on, and learning from that experience. Moreover, the context of the training activities might differ in terms of participants' prior knowledge and education level, since they are elements that contribute towards a better assessment of cyber range learning applicability in different formats. Nonetheless, the training facilitators are considered to determine the required level of skills to construct the training and assist the participants with the learning process.

Finally, step 5 aims to summarise and outline all the information, highlighting the analysis's key takeaways and developing concrete action points for educators in assessing the cyber range usability and how such technologies could be introduced and applied in classroom settings.

The ECSF (ENISA, 2022) details the distinctive attributes inherent in each cybersecurity role profile, outlining the competencies, skills, and knowledge requisite for cybersecurity practitioners (Briones Delgado et al., 2023). The framework also facilitates the development of educational curricula and acknowledges the proficiency of experts (Briones Delgado et al., 2023). Furthermore, it simplifies industry practices by providing a detailed document outlining appropriate tasks and required skills, thus, supporting recruitment for cybersecurity jobs.

From the 12 profiles listed in the framework, the authors focus on roles appropriate for cyber range training since these positions require various technical and interpersonal skills. Subsequently, the chosen roles are only mentioned briefly due to space constraints: Cybersecurity Threat Intelligence Specialists (CTIS), Cyber Incident Responders (CIR), Digital Forensics Investigators (DFI), Penetration Testers (PT), Cybersecurity Implementer (CI), Cybersecurity Educators (CE). Interested readers are referred to the ECSF framework (ENISA, 2022) for comprehensive details.

## 4 Insights on Cyber Ranges

Most cyber ranges are designed to train individuals and teams with hands-on skills. However, not all cyber ranges prioritise learning; instead, they focus primarily on providing participants with various scenarios and situations to practise their skills. Consequently, we reviewed the learning format and training appropriateness based on ENISA profiles, facilitator, roles, and target audiences. The information gathered from the 10 surveyed papers are presented below.

The approaches to learning in cybersecurity education vary across studies, reflecting different priorities and methodologies. Weiss et al. (2015) note a minimal focus on the learning process, although the training offers diverse scenarios. In contrast, Čeleda et al. (2020) describe a semester-long learning format involving the creation of a game tailored for the cyber range that aligns strongly with Kolb's experiential learning model. Similarly, Oh et al. (2020) put more emphasis on learning formats despite incorporating exercises based on curriculum guidelines to establish learning outcomes. Cruz et al. (2021) advocate for active learning principles, employing a structured approach of theoretical, cyber reconnaissance, and actual attack phases, fostering collaboration and individual reflection. Assessing the adherence to Kolb's framework in the study by (Erdogan et al., 2021) presents challenges. Despite outlining multiple evaluations during course preparation, the authors suggest the presence of some iteration through Kolb's steps. Vekaria et al. (2021) describe a learning method organised around three checkpoints: Learn - apply - create, well-aligned with Kolb's framework and supportive of gaining in-depth knowledge. Langner et al. (2022) emphasise that the educational process is a multifaceted domain that requires various elements to function and provide professionals with comprehensive skills, while incorporating aspects of the learning process into their format. Although not explicitly following Kolb's framework, the proposed training program is structured around similar principles. Conversely, Russo et al. (2023) highlight a sequential learning model that may result in unequal skill development among students, underlining the need for more support and time for reflection. Meanwhile, Lazarov et al. (2023) call for a focus on learning within their analysis of platform functionality and student engagement, indicating the need for further integration of the learning process into lectures. Finally, (Nespoli et al., 2024) point out a complete absence of consideration for learning within their study.

As the surveyed papers showed, the target audience for cyber ranges consists of high school students with engineering background, undergraduate and master's students in computer science, and professionals from companies or public institutions. Additionally, considering diverse learner backgrounds, it is vital to structure the learning process iteratively to ensure equitable knowledge attainment and facilitate peer learning.

However, cyber ranges serve as robust environments that inspire and empower students to develop comprehensive competencies. Several articles highlight strategies for equalising skill levels, including structured courses or module segmentation, which enhance learning through continuous assessment of progress and recognition of achievements. The implementation of a stratified teaching method enhances the learning experience, accommodating diverse skill levels and facilitating advancement. Furthermore, aligning roles and skills with industry ensures thorough learning and relevance to job market demands.

Table 1. Summary of the surveyed papers.

| Reference | ENISA Profile | Audience | Reaching Skills Equality | Facilitator |
|---|---|---|---|---|
| (Weiss et al., 2015) | CE, CI, DFI | College | Not Considered | Not Mentioned |
| (Čeleda et al., 2020) | CE, CI, PT | Undergrads | - Starting with a lecture on the topic<br>- Emphasise growth by facilitating discussions. | University-level educator |
| (Oh et al., 2020) | CE, CI, PT | Undergrads | No Information given. Not considered | University-level educator |
| (Erdogan et al., 2021) | CE, CTIS, Cyber Risk | Undergrads | - Required introductory course<br>- Course structured into smaller modules with individual contributions | E-learning format<br>No facilitator |
| (Cruz et al., 2021) | CE, CI, PT | Undergrads | - Initial Phase Equalizes Skill Levels | University-level educator |
| (Vekaria et al., 2021) | CE, CI, CIR | Undergrads | Levels: Beginner; Intermediate; Expert | University-level educator |
| (Langner et al., 2022) | CE, DFI | Undergrads | - Uniform Initial Knowledge<br>- No experience | Unclear |
| (Lazarov et al., 2023) | CE, CI, DFI, PT | Undergrads | -Tailored CTFs on Skill Levels<br>-Beginner Integration | University-level educator |
| (Russo et al., 2023) | CE, CI, DFI, PT | Undergrads | - Stratified Teaching Approach<br>- Topic Presentation Initiation | White Team / Green Team of Cyber Range |
| (Nespoli et al., 2024) | Unclear | Undergrads<br>Postgrads<br>Ph.Ds | Not Considered | University Researchers<br>Students<br>ITC Professionals<br>Security analysts |

# 5 Recommendations

The prior section depicts educational approaches where cyber ranges were used as environments for teaching cybersecurity due to their design, versatility, and robust scenario capabilities. Nonetheless, it is crucial to emphasise the learning component as much as the technological aspect to fully leverage the potential of this technology and ensure learners acquire the complex skills demanded by the job market. Therefore, this section aims to streamline the process of incorporating cyber ranges into teaching by outlining key considerations before integrating them into classroom formats.

**Educational Need:** It is essential to identify the competencies we aim to convey. Whether focusing on specific skills, like penetration testing, or fostering comprehensive cybersecurity profiles encompassing technical, personal, and interpersonal skills. While cyber ranges offer diverse capabilities to address cybersecurity competencies, they can also be complex environments that pose a risk of losing learners due to steep learning curves for training on specific tools or skills. Therefore, we recommend to explicitly plan their utilisation and alignment with learner needs, together with the incorporation of other teaching tools that may be available.

**Training Structure:** Allocating sufficient time for preparation, experimentation, and reflection is imperative to recognise diverse learning styles. We propose that the training structure should comprise Pre-Phase, During-Phase, and Post-Phase activities. The Pre-Phase includes brief traditional lectures to introduce essential concepts, followed by hands-on experimentation in the During-Phase, where the participants work individually or in groups towards learning objectives. Finally, the Post-Phase encourages reflection and collective learning through experience sharing. Moreover, we emphasise breaking down the steep learning curves by letting students learn one tool/method at a time and later combine the newly acquired knowledge in more complex scenarios.

**Technological and Facilitator Considerations**: Cyber ranges have evolved significantly, but their development and maintenance require extensive skills. Despite potentially higher costs, publicly available and online-hosted toolsets are recommended to streamline scenario creation and debugging. The choice between locally hosted or pay-by-use frameworks depends on team size and exercise complexity. Facilitators are essential in coordinating and supporting teaching activities while fostering constructive discussion. Therefore, we would like to point out that there is a need to empower and train facilitators to be able to use cyber ranges without the need for extensive background knowledge about either the technical platform or the scenarios, making cyber ranges more widely used. Lastly, the evaluation should focus on the student's progress rather than solely on achieving the scenario goal.

**Student Experience**: Learners' experience is crucial for developing personal and interpersonal skills. While goals and points can motivate, they may also discourage struggling students. We encourage individualised attention to ensure everyone feels included, although achieving it consistently and for everybody is challenging. Each student should be integrated into the teaching process to ensure inclusive learning environments. Furthermore, it is also essential to consider how a more diverse audience can be attracted to cybersecurity, which diverse approaches to learning and diversification of the content provided can support.

**Challenges and Limitations**: Addressing the challenges and limitations highlighted in the studies involves careful consideration of various factors:

1. The duration of the training is a constraint that must be carefully balanced with the depth of learning required to attain the desired competencies within the set timeframe. This sensitive equilibrium is a crucial consideration in practical cybersecurity training. Implementing such training in company environments poses challenges due to logistic and organisational constraints.

2. The lack of direct hands-on experience in some courses and the reliance on static learning methods may hinder the acquisition of practical skills.
3. The need for referenced documents and theoretical frameworks for constructing cybersecurity training courses may impede the development of structured and comprehensive educational programs.
4. Point-based evaluations tied to specific outcomes may overlook the holistic nature of learning and hinder student progression. It is crucial to ensure that all students, regardless of their level of skills, are adequately supported throughout the learning process to prevent anyone from being left behind.
5. The facilitator's role should be explicitly defined to guide and support learners.

Ultimately, integrating learning as an integral and vital component of the cyber ranges is essential for fostering a meaningful educational experience and ensuring that cybersecurity training effectively prepares students for real-world challenges.

# 6 Conclusion

To conclude, this study explores the integration of cyber ranges in educational settings for teaching cybersecurity, employing the Kolb framework to underscore the iterative nature of learning. It emphasizes the consideration of technical, personal, and interpersonal competencies, highlighting the holistic nature of teaching. Additionally, the importance of addressing skill equality and the role of facilitators in the educational process are highlighted. However, the literature suggests a need for greater emphasis on teaching and specific planning to integrate cyber ranges into the classroom fully. Despite the readiness of the technology, consistent planning for utilization still needs to be improved in the community. Therefore, prior to integration, it is imperative to reassess the audience's educational needs, develop training structures that consider student experience, and evaluate suitable technology while ensuring facilitators are comfortable with its use.

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# Rainwater Potabilization System: a PBL Experience for the Construction of Approached Technologies

Leonardo León Rojas[1 2], Alexei Ochoa-Duarte[2]

[1] Colegio Atenas, Bogotá, Colombia
[2] Universidad Nacional de Colombia, Bogotá, Colombia

Email: alleonr@unal.edu.co, agochoad@unal.edu.co

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**Abstract**

This document describes the successful experience of a rainwater potabilization system developed within the framework of the PEAMA Sumapaz program of the Universidad Nacional de Colombia, in Bogotá. This system was developed at the Colegio Nuevo Horizonte sede D Torca, located in the rural area of Usaquén, Bogotá, through the practical application of concepts such as approached technologies, social appropriation of technology, socio-technical adequacy, Humanitarian Engineering and Engaged Engineering, through the methodology of Problem and Project Based Learning. This project was carried out during the second semester of 2022 and the whole 2023, in an interdisciplinary way, with the participation of students of economics, mechatronic engineering, mechanical engineering, civil engineering and agronomic engineering, who put into practice the knowledge acquired in the subjects they were taking at that time, and with the support of experts in the corresponding topics. The rainwater potabilization system was installed in the school, meets the physicochemical and microbiological parameters for human consumption and is functional, managed by students from the school and PEAMA Sumapaz, who were given the corresponding training. However, it continues to be improved and made more complex by the students who participated in its development, as well as by other PEAMA students and members of the school community.

**Keywords**: PBL; Humanitarian Engineering; low cost technologies; Engaged Engineering.

## 1 Introduction

This document gathers a successful PBL experience within PEAMA Sumapaz, from a critical point of view taking as a reference the concepts of humanitarian engineering and engaged engineering, and whose success is measured from the achievement of the social appropriation of the technology by the community involved.

The research was carried out in a multi-methodological way, through 1) the review of bibliography on the PEAMA Sumapaz, documents made by the students of the rainwater potabilization project, 2) the participant observation, since the authors have been an active part of the process and 3) semi-structured interviews made to members of the academic community of PEAMA Sumapaz, elaborated in the framework of Leonardo León's postdoctoral stay at the *Instituto De Estudios Ambientales* of *Universidad Nacional de Colombia*, whose research was entitled "PEAMA Sumapaz, a model of education for development? "and which also served as a background and basis for the present work, since it analyzes how students learn in the program through the PBL methodology.

This paper is divided into eight sections. First, we describe the context of PEAMA Sumapaz and nodo Torca. Then, we present the PBL Methodology used in this program. Next section presents the conceptual framework of this research composed by the concepts of Engaged Engineering and Humanitarian Engineering. This is followed by a description of the rainwater purification system, as well as the process of social appropriation of this technology by the community. Finally, learning outcomes, future work, and research conclusions are presented.

## 2 Context of Peama Sumapaz and nodo Torca

Based on the results of interviews with members of the Sumapaz community, students of the program and one of the creators of PEAMA Sumapaz, this program is the result of peasant struggles in the Bogotá town of Sumapaz, a territory hit by social and armed conflict, and with a high degree of social organization. This population had requested for years the presence of public education in the territory, with a contextualized model, since the majority of young people in the town could not access higher education and those who managed to do so were due to a great effort by their families, and at the cost of a process of depeasantization that forced young people to leave their territories and lose many of their customs in that transit. This contributes to the exodus and, therefore, to the lack of generational change in field work. Furthermore, the only job offer for professionals that continues to exist in the territory is as officials or contractors in institutions, without a peasant focus.

In this sense, PEAMA Sumapaz It is a special admission program, which began in 2016, as an accord between *Universidad Nacional de Colombia* and Bogotá city hall. It seeks to openuniversity access to high school graduates who normally would not have it due to lack of resources and low admission scores. Under this program, students stay in the node for 4 semesters before going to the Bogotá campus (Gaitán-Albarracín, 2018; Cita Triana et al, 2020). Currently, the program has 3 nodes of action*: Nazareth, Torca* and *Ciudad Bolivar*. In each of the nodes, classes have a Project-Based Learning approach, whereby in each semester an integrative project is carried out in interdisciplinary groups (Rodríguez-Mesa, 2023).

Torca is a rural zone in the north of Bogotá. In this site, it is *Nuevo Horizonte* School, a public institution where one of the nodes of PEAMA Sumapaz take place. This node is for students who graduated from a rural school in the localities of *Suba, Usaquén, Chapinero* and *Santa Fe*. It is close to a forest reserve, and it does not have access to potable water.

## 3 PBL Methodology in PEAMA Sumapaz

The quest for authenticity in learning, brings about the need to align educational experiences with real-world STEM (Nicholas & Scribner, 2021; Ochoa-Duarte, León Rojas & Reina-Rozo, 2021). In addition, PBL is an effective teaching and learning strategy, as it allows for longer retention of learned concepts, improves problem-solving skills and enhances critical thinking, and has shown good results for rural education (Osman & Krieg, 2021). Moreover, the lack of access of rural students to high quality educational resources causes a delay in academic performance and a deficiency in competencies (Cheng, & Carolyn Yang, 2023), which processes such as PEAMA Sumapaz seek to diminish.

Thus, PEAMA Sumapaz has been built from the framework of constructivist education, particularly from the Project-Based Learning methodology. Under this model, students must develop a project in interdisciplinary groups, throughout the academic semester, framed in the subjects they are taking and based on a problem from a community, hopefully from the rural areas of Bogotá and related to the PEAMA environment.

### 3.1 Description of PEAMA Sumapaz model

Those who enter PEAMA Sumapaz must go through an academic process in three phases. In the first, students take the subjects under the Project Based Learning (PBL) methodology in the territory, for three or four semesters, depending on the degree. In the second phase, students do academic mobility to the Bogotá campus, where they study the other subjects. In the final phase, the degree work must be done returning to the rural communities of Bogotá, so that there is a greater probability of remaining in their place of origin after graduation and there is a return to the territory.

According to the relevant actors in the creation of the program, the main objective of PEAMA Sumapaz is to provide a differential and consistent mechanism of access and permanence in the institutional, economic, pedagogical and psychosocial aspects to young people from the rural areas of Bogotá to Universidad Nacional de Colombia, taking into account the low educational offer that exists in those areas, so that knowledge relevant to their contexts is built, contributing to local development, contributing to the care of the ecosystem and strengthening the relationship between the academy and the communities, through the Project Based Learning methodology.

From a pedagogical point of view, there has been an effort to break with banking education, betting on a constructivist model through the PBL methodology, since the concept is rooted in experiential experience, as opposed to the behavioral tradition. Hence, great importance is given to the development of skills considered vital such as learning to read, observe, construct questions, propose hypotheses (Gaitán-Albarracín, 2018), as well as work as a team and reach collective consensus. , since these are fundamental for an active teaching-learning process that enhances creativity.

The hegemonic academy, framed in the coloniality of knowledge, has not only excluded different knowledge but also the subjects who carry it, thus discriminating against popular knowledge (Guido-Guevara & Soler-Martín, 2023). In the case of PEAMA Sumapaz, the intention is to put the knowledge of the communities in dialogue with academic knowledge during the development of the projects. However, there is a permanent tension here, since it does not always occur, since it depends on many factors, such as the abilities, interests and knowledge not only of the students but also of the teachers who guide them in the learning process, as well as of the intended or actually achieved scope of the projects and whether they continue or not.

# 4 Engaged Engineering and Humanitarian Engineering in praxis

This section shows the concepts of engaged engineering and humanitarian engineering, which have been worked on by the authors of this paper and which serve as a framework for the analysis of the experience of the rainwater potabilization system project.

Engaged Engineering is a broad concept aimed at encompassing engineering practices that transcend the ethical boundaries of traditional engineering, fostering a more inclusive relationship among science, technology, and society (Ochoa-Duarte & Reina-Rozo, 2022). This approach strives to incorporate a range of practices and methodologies that benefit diverse populations. It involves initiatives within engineering institutions, inclusive development actions, the establishment of new educational guidelines, collaborative efforts with marginalized communities, non-profit organizations, social enterprises, and social technology networks, among others (Kleba, 2017; Ochoa-Duarte & Reina-Rozo, 2022).

Therefore, the concept of Engaged Engineering embraces diversity by integrating various approaches and a wide array of practices, methodologies, and perspectives aimed at advancing science and technology for the betterment of society, aligning closely with the Engaged STS program (Sismondo, 2008). In doing so, it seeks to surpass the ethical limitations of traditional engineering and reframe the relationships between engineering, nature, and society over time (Catalano, 2006).

Under the umbrella of Engaged Engineering, we find Humanitarian Engineering, which can be defined as the convergence of community knowledge, human sciences, science and technology in engineering praxis. Through the co-creation of teaching, reflection, research, innovation and manufacturing processes, the empowerment and technological appropriation of communities is strengthened. This allows the generation of solutions to circumstances that put marginalized populations at risk or in a state of vulnerability, in a way that promotes good living within the community, understood as harmony in the relationship with others, with nature, and with himself, through ethical action (León Rojas, 2020).

Humanitarian engineering and engaged engineering, in praxis, correspond in this context to how, from teaching practice, students design and execute high-impact projects in their communities, while learning their disciplines. This is a constructivist approach, in which it is conceived that knowledge is not given but is constructed during the pedagogical process, generating appropriation of science and technology by students and other members of the communities in a way active, while contributing to the solution of real problems (Ochoa-Duarte, León Rojas y Reina-Rozo, 2021).

Project-based learning allows the development of these two concepts in depth, since the students learn by doing. Also, this methodology leaves the epistemological framework of Western science, and values other experiences and knowledge. In addition, the most important thing is that the pedagogical process does not remain in a simple characterization of the problems, but goes beyond, designing and building technological solutions, both appropriate and low cost, benefiting a community, including it in the different phases of the projects and not in an instrumental way (Cruz, Ochoa-Duarte & León, 2023).

## 5 Description of the water potabilization project

This section presents the general description of the design and construction process of the rainwater potabilization system, through participant observation and documentation of the project done during three semesters by the PEAMA Sumapaz students involved.

Considering that the school's most important problem is the lack of access to drinking water, students from the *Torca* node proposed a rainwater purification system in the second semester of 2022. From that academic period until the second semester of 2023, this group of students designed, manufactured, assembled, tested, implemented and improved the rainwater purification system.

In 2022-2, the group consisted of six students who were in their second semester in agronomy engineering, civil engineering, mechanical engineering, mechatronics engineering and economics. During this period, they designed and executed a pilot plan, using the infrastructure of a room designed to collect rainwater, as shown in figure 1. The result was poor, because it did not meet expectations and because they did not consider a process of social appropriation of the technology. However, the group committed itself to solve all the drawbacks, both internal and external, that did not allow a functional system. This decision was fundamental for the future success of the project, since it is common that every time an academic period is completed, a new project is started the next one, especially when the results were not successful.

Figure 1. First potabilization system

Thus it was that in 2023-1, the same group of students resumed the project, improving the prototype built previously, leaving it functional, although the physicochemical and microbiological properties did not fully comply with the parameters established for the water to be drinkable. This time workshops were held with school students and an operating manual was made, although with errors, in pursuit of social appropriation of the technological system, as shown in figure 2. Although there was significant progress compared to the previous semester, it was still not ready for use and there was a latent danger that all the accumulated work would be lost, since there was already pressure from PEAMA Sumapaz teachers to show concrete results or start a new project.

So, in 2023-2, the group decided to fulfill the commitments made to the school community and as an act of dignity, they insisted on continuing and finishing what they had proposed. This time they had two fewer members because one of them made the transition to the main campus of the university and the other was expelled from the university due to poor academic performance. In addition, the fact that three students in the group enrolled in the Electronics Workshop course played in their favor, since it allowed them to explore new perspectives and devices to implement in the water treatment system and because it made them take more interest in mechanical engineering and mechatronics engineering careers. In this period the progress was more significant, there was joint work with school students, a management plan was delivered and the system was functional. Besides, this project was presented at the *IV Encuentro Colombiano de Ingeniería y Desarrollo Social* (ECIDS) in Pereira (Polania & Quiroga, 2023).


Figure 2. Second potabilization system and workshop with the community

Although the idea was that from 2024-1 the purification system would be solely in charge of the school community, it was fortunate that first semester students decided to do a project based on the installed device, adding a centrifugation system of filtered water to avoid colony-forming units, taking into account that there is now an industrial design career at PEAMA Sumapaz.

## 6 Social appropriation of the potabilization system

Social appropriation of technology is a process in which citizens and communities use technological tools consciously and intentionally, recognizing their usefulness for educational, labor and social development. This process involves an active and participatory interaction with technology, where users not only adopt and use it, but also explore, evaluate and adjust it to meet their specific needs. It is a dynamic process that goes beyond simple adoption, generating changes in both user practices and in the technology itself (Lozano Borda & Pérez-Bustos, 2012). In the digital era, especially during situations such as the pandemic, the social appropriation of technology becomes fundamental, given the crucial role played by information and communication technologies in educational and work environments (Dávila-Rodríguez, 2020).

Figure 3. Tank truck that supplies the school

The project had an important component of social appropriation of technology that, although late, was successful in two ways. On the one hand, towards the school community, by making it part of the process and, on the other, within the PEAMA Sumapaz community, which is something little addressed when talking about social appropriation. To achieve this, we started from a deep understanding of the concepts of appropriate technologies and low-cost technologies, which imply knowledge of the territory, contextual design and use of environmental resources.

The first thing is that the project arose from a problem at the school: the lack of access to drinking water. To solve this problem, several options have been sought, among which is the use of a tank truck (figure 3), which is the way in which the school has been supplied, but, due to poor management of the storage tanks, the water becomes contaminated sooner. to reach the taps. Furthermore, in this search for solutions, the last two rooms that were built were built with roofs designed to capture rainwater, which is why one of them was used for the purification system. The starting point was, then, an infrastructure already adequate for the system and a prioritization of the problem by the school community.

Then, with difficulties and delays, school students were incorporated into the process, so that they learned about the existence and operation of the water treatment system, through practical workshops and discussions within the framework of the event "Art and Rurality" that takes place every year at the institution. Thus, tenth grade young people were empowered to take charge of maintaining the system, while several children, little by little, began to trust the device, so that they now drink water from it, as shown in figure 4.

Figure 4. Children using the potabilization system

The relationship between PEAMA Sumapaz students and the school community grew closer thanks to the rainwater purification system, which facilitated the joint realization of other projects such as hydroponic cultivation in the school greenhouse, which has been developing horizontally between the different actors that converge in the territory.

On the other hand, despite several setbacks at the beginning of the project, the students in the group increasingly took ownership of the purification system. At first, they saw it as a simple requirement to be able to take the subjects in a manner consistent with the PBL, so they did it in an undisciplined manner, without independent work and dependent on the PEAMA Sumapaz tutors. However, as the results were obtained, it became a personal and collective challenge for the members of the group, of which they are proud, to the point of taking it to the IV Colombian Meeting of Engineering and Social Development (ECIDS in Spanish) in Pereira in 2023. In addition, managed to convince several students who recently entered PEAMA Sumapaz in 2024-1 to continue improving the system.

Finally, what we consider most important in terms of the social appropriation of technology is the fact that two students in the group have continued working on the purification system, no longer to solve the specific problem of the Nuevo Horizonte School, but to achieve scale it, so that it can be implemented in other places in the country with the same problems and similar conditions. This is summarized by Figure 5.

Figure 5. Final potabilization system and workgroup

## 7 Learning outcomes and future work

The interdisciplinary approach used in this project not only allowed students to acquire technical knowledge, but also skills in teamwork, effective communication and complex problem solving in a real-world environment. By forming groups of students from different fields, participants were able to integrate diverse perspectives and approaches, thus enriching their solutions and fostering creativity and innovation. This type of experience not only gives them a broader view of engineering, but also prepares them to face real-world challenges that require holistic and collaborative solutions.

The social innovation promoted through this project highlights the importance of not only developing effective technologies, but also ensuring their positive impact and long-term sustainability in communities. Students learned to consider ethical, cultural and environmental aspects in their designs, prioritizing the well-being of people and the environment. This social and environmental awareness enables them not only to become competent engineers, but also agents of change committed to Buen Vivir of the communities, understood as the construction of harmony with nature, other human beings and ourselves (Hidalgo-Capitán et al., 2019). In this way, engineering education is transformed and dialogues with concepts such as Engaged Engineering, in order to contribute to the transition towards Buen Vivir (Ochoa-Duarte, 2024).

On the other hand, students were able to learn disciplinary concepts of engineering and economics, such as electronic circuits, physical infrastructure, machine design, technical drawing, cost analysis, computer programming, economic engineering, irrigation systems, among others. All this within a real context, in a much more enriching way than the abstract learning that takes place in a classroom on campus.

So, the lessons learned by the students who participated in the project include the experience of participating in a fully contextualized engineering project, in which through Engaged Engineering and Humanitarian Engineering, and by doing interdisciplinary work, a dialogue of knowledge is established to allow transforming realities. In this way, they learn about the importance of breaking with the conventional way of doing engineering, in which the community is seen as a user and nature is taken as a resource. Thus, through this experience, the students learn much more than the contents of the subjects, but rather they orient their work as students and future professionals in a field that seeks to confront the civilization crisis in which we currently live.

The future work is mainly from students who participated in the rainwater potabilization project, because they want to develop a potabilization system for other communities with the same problem. To achieve this, it is important that they continue working autonomously, in an interdisciplinary manner and incorporating the dialogue of knowledge, in order to continue favoring the social appropriation of technology. This is of great importance because the geographical, ecological, social and cultural diversity of the country means that each co-design and co-creation process must be adapted to its own context.

# 8 Conclusions

PEAMA Sumapaz program presents an innovative educational proposal that seeks to promote access and permanence of young people from rural areas of Bogotá at the Universidad Nacional de Colombia, through a pedagogical approach based on Project Based Learning (PBL). This approach, focused on the construction of knowledge relevant to local contexts, contributes to the Buen Vivir of communities, the care of the ecosystem and the strengthening of the relationship between academia and communities. The importance of this program is highlighted in breaking with traditional banking education, betting on a constructivist model that fosters essential skills such as observation skills, question formulation, hypothesis proposal, teamwork and collective consensus, fundamental elements for an active teaching-learning process that enhances creativity and critical thinking.

Despite the challenges inherent to the integration of popular and academic knowledge, PEAMA Sumapaz program represents a significant effort to bring this knowledge into dialogue during the development of the projects. However, a constant tension is evident due to various factors such as the skills, interests and knowledge of students and teachers, as well as the actual scope of the projects. In spite of these difficulties, the program demonstrates a commitment to the inclusion of diverse knowledge and the promotion of meaningful learning that transcends the traditional boundaries of education, contributing to the integral formation of students and strengthening the relationship between academia and local communities.

Regarding the projects carried out in PEAMA Sumapaz, first of all, the importance of adopting an interdisciplinary and collaborative approach to solve complex problems is highlighted, recognizing the diversity of perspectives and knowledge as a fundamental asset for innovation and effectiveness of the proposed solutions. In addition, the need to transcend the conventional vision of engineering, integrating social, environmental and ethical aspects in the development of technologies that have a positive impact on communities is evident.

Finally, the importance of promoting the social appropriation of technology through the dialogue of knowledge and co-creation with local communities is highlighted, ensuring the relevance and sustainability of the implemented solutions. This approach not only strengthens the relationship between engineering and society, but also empowers students as agents of change capable of addressing current challenges from a comprehensive and committed perspective.

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# Making Visible the Invisible: Experiences on Multidisciplinary Outdoors Groundwater Teaching at Bogotá Campus

Eduardo Torres-Rojas[1], Hernán G. Cortés-Mora[1], Rosa A. Botello-Yañez[1], Carlos E. Ángel-Martínez [2], Leonardo D. Donado[4], Adriana Piña[4], Martha C. Bustos-López[5]

[1] Oficina de Gestión Ambiental, Universidad Nacional de Colombia, Sede Bogotá
[2] Departamento de Geociencias, Universidad Nacional de Colombia, Sede Bogotá
[3] Facultad de Ingeniería, Universidad Nacional de Colombia, Sede Bogotá
[4] Laboratorio de Ingeniería Ambiental, Facultad de Ingeniería, Universidad Nacional de Colombia, Sede Bogotá

Email: edtorresro@unal.edu.co, hgcortesm@unal.edu.co

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**Abstract**

Groundwater is a vital natural resource that brings over 50% of water supply systems and 45% of irrigation worldwide. However, like the well-known global pattern, groundwater still needs to be better understood and managed in Colombia, leaving several knowledge gaps among all stakeholders, from the citizens and the engineering and geosciences students and practitioners to the policy and decision-makers. In Bogotá, the country's capital, where the water supply comes predominantly from surface water, misconceptions and a mystic veil around groundwater prevail. This work presents the cooperation work performed by the Oficina de Gestión Ambiental of the Universidad Nacional de Colombia Sede Bogotá, together with engineering and sciences faculties through the last three years to project the value of the Bogotá Campus as an outdoors laboratory for teaching about groundwater to undergraduate and graduate level while information is gathered to support the campus management. Geosciences and engineering professors' wide range of interests in groundwater converge on the campus, where interdisciplinary practices that otherwise would take place in distant places, much of the time without the required conditions, can be held. Over the last three years, more than 100 undergraduate and graduate students have participated in groundwater-related activities, including water level measurement, hydraulic testing, physicochemical and isotopic sampling, and monitoring well construction. These practices let the students learn on and about the campus, making them conscious of the University's challenges and encouraging the development of new projects to resolve them while acquiring critical thinking. Finally, the work supports the University's goals in its Environmental Policy and changes the university decision-makers mindset about groundwater's potential for further campus development.

**Keywords**: Groundwater; Cooperation; Environmental Policy; Teaching and Research.

## 1 Introduction

Most of Earth's liquid freshwater is groundwater (about 98%) (but we don't "see" it); the rest is surface water (what we see) (UNESCO, 2022). This freshwater supports surface ecosystems (including humans and their needs). In the context of the current global water crisis, groundwater contributes to achieving 7 of the 17 Sustainable Development Goals –SDG- (The Groundwater Project, 2020) but for this to be a reality it is necessary to have adequate knowledge about it. In Colombia, 80% of the territory does not have sufficient studies on groundwater, and there are large gaps in the educational system in this regard.

Teaching about groundwater is a challenging task due to the invisible nature of subsurface processes and the problems in experiencing it directly, even in countries where this resource represents one of the most important sources of drinking water supply (Dickerson, Penick, Dawkins and Van Hoz, 2007). The interdisciplinary study of groundwater, hydrogeology, requires strong practical training to obtain reliable data in the field that will later be analyzed. Field practices have been identified as a valuable tool for groundwater education in a balanced and iterative cycle with theoretical and laboratory sessions (Gleeson, Allen and Ferguson, 2012). This practical training has the potential to significantly improve our understanding and management of groundwater, giving us hope for a more sustainable future.

The National University of Colombia is the country's main public university, with nine campuses throughout the country, with Bogotá being the largest. With more than 127 hectares, of which almost 75% is non-built area, the university city has 11 schools in all areas of knowledge, where environmental management is configured as a support for the management activities of the University and an articulator with academic activities. The Environmental Management Office (OGA) of the Bogotá Campus is a department attached to the vice-chancellor's office that aims to incorporate the Environmental dimension in the Campus processes, both in the fulfillment of its main activities as well as in the support and management, through actions of education, appropriation, prevention, mitigation, control and compensation of environmental aspects to comply with legal requirements within the framework of the SDG. It must ensure compliance with the University's environmental policy at the Bogotá Campus, from a perspective of University Environmental Responsibility, and of this with external actors.

Here we present our experiences of the last three years regarding the use of the Bogotá Campus as a practice center (Torres-Rojas & Ángel-Martínez, 2020) based on the cooperation established between the OGA, professors and students to promote active learning of hydrogeology in the fields of engineering and science.

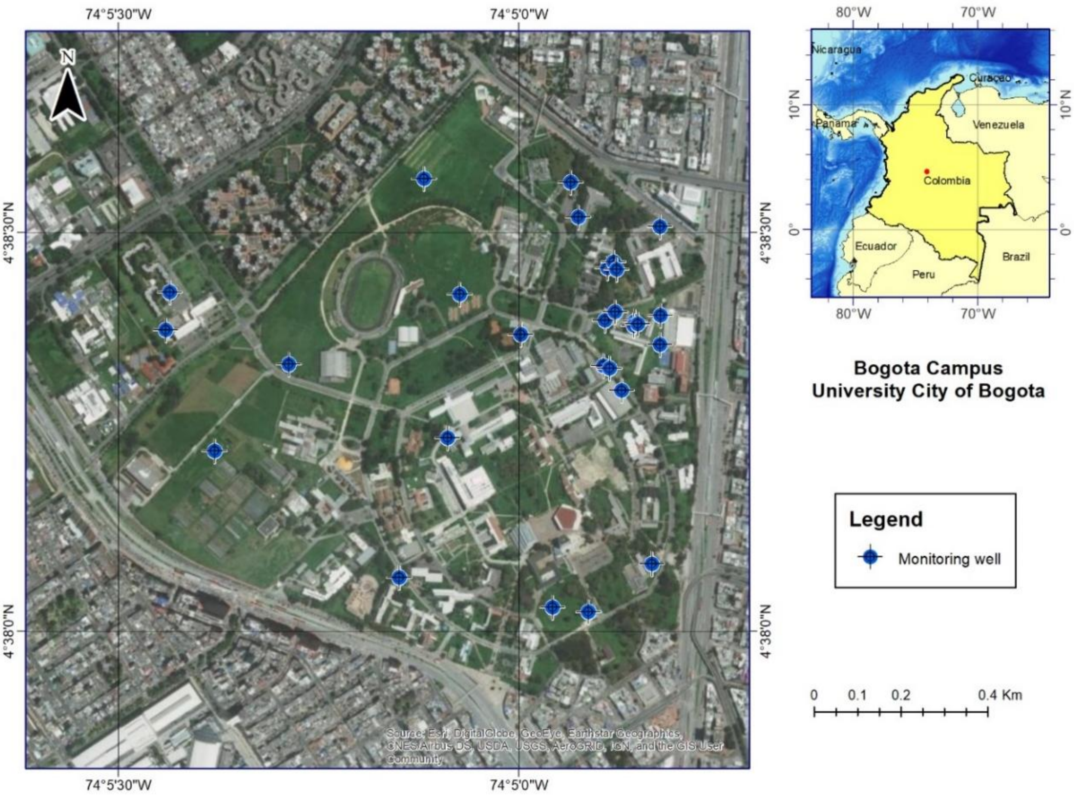


Figure 1. Location map of the Bogotá Campus - University City of Bogota and the groundwater monitoring network

## 2 Geologic and hydrogeologic context – Monitoring well network

The Bogotá Campus is located on the sediments originated by an ancient lake of Pleistocene age. The subsoil is composed of the intercalation of clays, silts and peat with minor beds of sand and gravel in the so-called Sabana Formation. Despite the prevalence of fine-grained sediments (aquitards) over coarse-grained sediments (aquifers), the Sabana Formation is considered a multilayer semi-confined aquifer. Despite the existence of more than 500 wells, dug wells and springs and their relevance to the industrial sector (Secretaria Distrital de Ambiente, 2023), knowledge about groundwater among the inhabitants of Bogotá is poor.

The OGA has established a groundwater monitoring network (Figure 1) composed of 29 monitoring points: a 275 m deep well and a 150 m deep piezometer, which provides information on the deepest part of the Sabana Formation and 27 monitoring wells ranging from 3 to 30 m deep, focusing mainly on the first 10 m of aquifers and aquitards on the Campus. The monitoring networks include both the existing infrastructures built by the Geological Service of Colombia and the university's Geotechnics laboratory. Recently, 8 new monitoring wells were built by the OGA to strengthen the monitoring network.

# 3 Methods

In a significant development in 2021, OGA procured state-of-the-art groundwater monitoring equipment and initiated strategic alliances with the Engineering and Science faculties. This collaboration aimed to gather data on the existing monitoring wells on Campus and historical groundwater level measurements conducted by student groups since 2016. Subsequently, systematic measurements of the water level were initiated. The historical and new data were then centralized in a geographic information system (GIS) database, which was made public, leading to data visualization through dashboards.

The cooperation scheme between OGA and teachers for improving outdoor groundwater teaching includes two educational contexts: in specific sessions of the classes (one or two per course) and in extra-curricular activities driven by the OGA or by student groups interested in deepening their groundwater knowledge. The first activity around groundwater between OGA and teachers took place at the end of 2021 with the leadership of the Geoscience Department, inviting the OGA as a guest to the first groundwater well inventory practice on campus carried out for the Hydrogeology class of the Geology undergraduate program. The practice used the existing monitoring network and the recently gathered information. This practice is now carried out semiannually. Then, due to the growing interest of Engineering teachers in using the Bogota Campus as an outdoor lab, a continuous wide range of activities was progressively added to groundwater-related classes of the civil engineering undergraduate program and the master in engineering (environmental and hydraulic resources), covering another groundwater point of view, including the study of i) the hydraulic properties of aquifers and aquitards by performing slug tests, ii) the physicochemical composition of groundwater by taking groundwater samples, analyzing it at the laboratory and interpreting the results and iii) the isotopic groundwater composition, by taking samples and shipping abroad for analysis to get insights regarding the contributing source (Bowen et al., 2019; Jasechko, 2019; Rozanski et al., 1993). Subsequently, in the last year (2023-2024), new practices designed for undergraduate and graduate subjects have been incorporated, where students participate directly by taking field data and then analyzing it (pump tests and slug tests).

Each outdoor practice begins with a brief introduction by OGA staff about the infrastructure that will be used in the practice and an update of the concepts seen in class by the teacher. The teacher and OGA's staff give some essential explanations about using the equipment and the procedures in the field and encourage the students to develop simple hands-on activities before carrying out the planned activity. The participating groups in the outdoor sessions commonly have at most 15 students, ensuring an engagement with the activities. Despite the particular nature of every class, the activities that take place in outdoor groundwater practices share the application of Cooperative-based learning techniques (Hernández-de-Menéndez, Vallejo Guevara, Tudón Martínez, Hernández Alcántara, & Morales-Menendez, 2019). For example, in Hydrogeology and Field Techniques classes practices, students form small groups and take the position of consultant firms or experts collecting information in the field, taking measurements and samples, and filling out the corresponding forms to later perform the corresponding analysis. During the practice, the teachers act as mentors, asking questions about the relevant topics of the practice, clarifying the students' doubts, and highlighting the key points.

In the analysis performed by students after the practices, several kinds of tools are used, for example, i) geologic to relate the subsurface materials with the groundwater flow and compositions, ii) hydrochemical to evaluate the interaction of groundwater with geological materials and how rainfall patterns affect the composition of the water, ii) isotopic, to analyze the hydrogen and oxygen isotopic abundance regarding the processes taking place during the water cycle at multiple scales (Bowen, Zhongyin, Fiorella, & Putman, 2019; Jasechko, 2019) and iii) hydraulic, to determine the geo-hidraulic parameters of the subsurface which controls the flow of groundwater.

Depending on the nature of the activities, students may generate new results, such as characteristic hydraulic values of aquifers or laboratory chemical tests. In such cases, the teacher, after conducting a quality control check, forwards the results to be uploaded to the OGA database. This establishes an iterative flow of information between the OGA and the students, bolstering the GIS database, which will serve as a valuable resource for future courses and research.

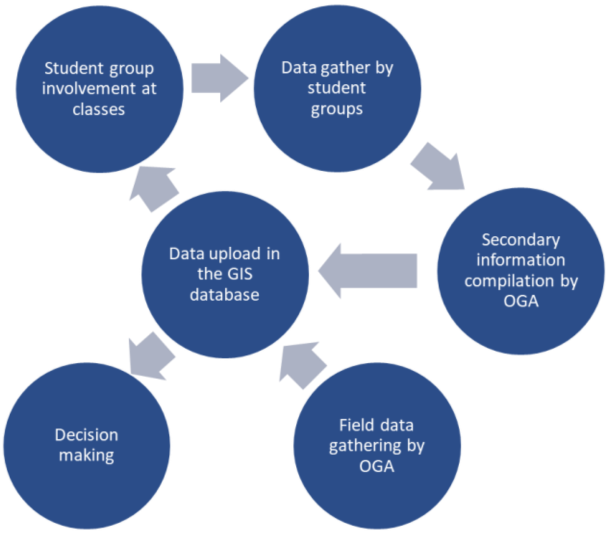


Figure 2. Conceptual model of the relationship between the OGA, teachers and students

Figure 3. Activities developed in the Bogota Campus. A) Students measuring the casing diameter of a well before take groundwater levels B) Monitoring well construction with the presence of geology and engineering students.

## 4 Results

Between July 2021 and April 2024, a total of 35 activities were developed at the Bogotá campus, with the participation of 247 students and five professors of engineering and sciences faculties. Considering that some could participate in more than one activity during this period, an estimated number of 225 benefited students is assumed. Most of the activities, 60%, were held with the Engineering Faculty, 31% with Geosciences, and 9% in activities led by the OGA. Most students, 61%, were enrolled in engineering programs, including undergraduate and graduate levels, 36% with the geoscience undergraduate program, and 3% with other programs. The practices covered a wide range of topics around groundwater, with 51% related with purging, and considerations about physicochemical and isotopic sampling, 23% with field techniques used in the recognition and description of wells and monitoring wells and the measurement of water levels, 11% with hydraulic testing by conducting pumping test and slug test, including a successful 49-h pumping test in the campus well and 14% with diffusion of the state of art of groundwater in campus and demonstrations about the activities and process related with the construction of monitoring wells (Figure 3 B), an unique experience in the geologist and engineers education.

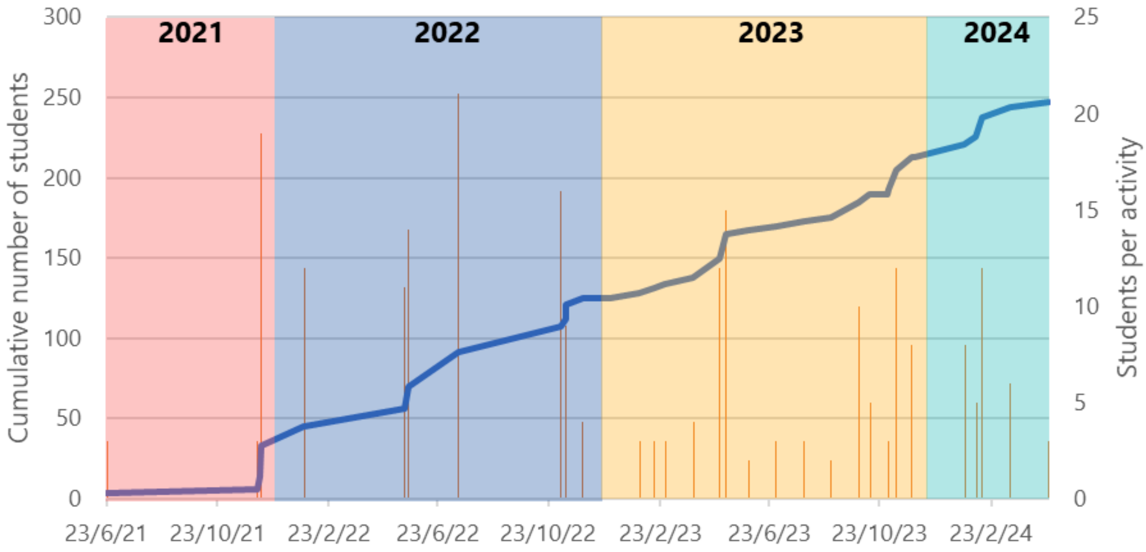


Figure 4. Cumulative number of students benefited between 2021 and 2024 differentiated by activities

Between 2021 and 2024 a total of 90 water samples were taken in the Bogota Campus, involving the hands-on experience of students in the process of purging, sampling and interpretation of the results. For 16% of the samples the students also participate performing the physicochemical analysis on the Environmental Engineering Laboratory of the University as part of the 2022 and 2023 Field Techniques classes. Figure 5 displays the graphic hydrochemical analysis perform to the dataset construct after the 2022 -2023 sampling campaigns using Piper and Gaillardet diagrams. These diagram are also examples of the free code interactive tools in Python available at the source code repository of the Environmental Hydrogeology class which can be access through the website: https://binder.projectpythia.org/v2/gh/Peter24K2G/Curso.git/HEAD). The results point out that the campus groundwater is bicarbonate between sodium – magnesic type (Figure 5b), with the presence of weathering of silicates such as montmorillonite. The piper diagram shows the water evolution from two end members: rain (TOT_HID) and the deepest aquifer tap by the Campus well [Piez_Ingeo], with mixing conditions for the shallow groundwater monitoring wells.

## 5 Discussion

As seen in Figure 4, the number of activities per year grew from 4 in 2021 to more than 17 in 2023, reflecting not only an increasing interest of professors in the use of the Campus for practices but also the number of students who have access to the unique groundwater physical spaces that the Bogota Campus offers an even participates on the groundwater monitoring network expansion recently made. In the outdoor practices described, a student-centered learning approach is applied. The solid hands-on component, which includes the wide range of aspects described around groundwater, linked with real-life situations faced by hydrogeologists and environmental sciences in field activities, engages the students and motivates them with the classes in a way that could not be achieved in a passive learning method.

The activities performed at the outdoor practices go beyond taking measurements and taking samples. For example, in the Field Techniques class, the professor promotes cooperative learning techniques in which the student works together and understands team dynamics, focusing on social skills such as leadership, communication, and conflict management (Gleason et al., 2011) required to perform the proposed task.

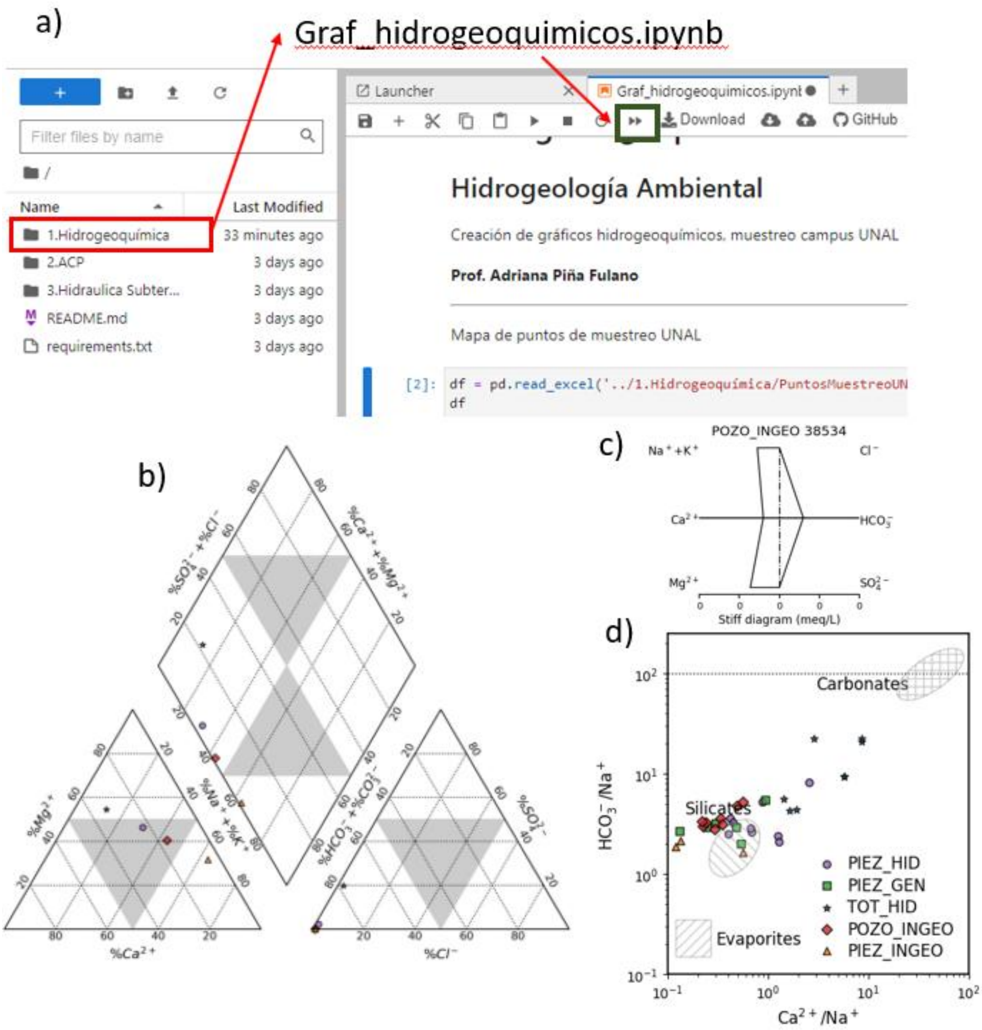


Figure 5. Hydrochemical analysis of groundwater in Bogota Campus. a) Source Code repository outline for graphic hydrochemical analysis https://binder.projectpythia.org/v2/gh/Peter24K2G/Curso.git/HEAD, b) Piper diagram of march 2023 samples showing the major ion water composition evolution c) Stiff diagram of the Campus well showing a bicarbonate sodium/magnesium water type, D) Gaillardet diagram showing the groundwater interaction with the aquifer, mainly silicate weathering.

The students faced not just planning a campaign, performing the proper purge (often overlooked by consultants), taking the sample, filling the corresponding forms, preserving the samples ultimately, and performing the dissolved species determination in the Environmental Engineering Laboratory of the University, using the proper standards (APHA, AWWA, & WEF, 2017). In the whole process, they deal with logistic matters, which often affect timetable fulfillment in many real-time sampling campaigns, improving the development of competencies such as collaboration, autonomy, logic, creative thinking, and problem-solving, added value of active learning pedagogical strategies (Hernández-de-Menéndez et al., 2019). The next step, after the sample analysis is available, is ease because of the acquired knowledge during the practices about the hydrogeologic setting. The flexibility that free code interactive tools in Python offer (see Figure 5) enhances the simultaneous visualization of an increasing dataset, letting the student identify trends and derive meaningful conclusions.

The learning goals converge despite the outdoor sessions, including geoscience and engineering perspectives. For example, after the practices, the students should be able to identify the differences between monitoring and groundwater wells, know how to properly take groundwater level measurements, and choose the appropriate procedure to take representative groundwater samples for physicochemical and isotopic analyses.

Finally, the information gathered during the outdoor practices contributes to progressively strengthening the OGA's hydrogeology GIS dataset, giving more tools to the next students participating in the Campus practices.

# 6 Next steps

Despite the progress gained during the last three years and the increasing interest of engineering and science teachers applying the active learning approach in the University City around groundwater, the next steps will be focused on tracking and evaluating the impact that the performed activities have on the level of student's conceptualization of hydrogeology and groundwater to improve the activities. The projected approach will include applying surveys on students attending future activities and former students. The outdoor practices, in conjunction with related concept tests, will also be used to assess students' comprehension of topics covered in the practices before or after class. Meanwhile, groundwater information will be gathered to enhance the available dataset for teaching and increase the insight of groundwater flow and composition in the Bogota Campus, supporting the OGA activities.

The growing information available for students, professors, and University decision-makers and the engagement established between these stakeholders eventually led to the retooling of the Bogota campus from a passive to an active environment for teaching and learning, establishing a living lab framework in a co-creative ecosystem, like the University of Manchester experience (Evans, Jones, Karvonen, Millard, & Wendler, 2015).

# 7 Conclusions

Between 2021 and 2024, 225 students of engineering and geoscience programs at undergraduate and graduate levels by the application took part in outdoor practices in the Bogota Campus of the Universidad Nacional de Colombia due to the cooperation between the Oficina de Gestion Ambiental and professors. This approach led the students to strengthen their knowledge by interacting directly with the groundwater campus, in cooperative based learning practices including water sampling, hydraulic test, and groundwater well inventory.

These practices that can be carried out in the campus infrastructure itself constitute an excellent advantage for the university, undergraduate, and graduate students (Science and Engineering). The respective professors facilitate learning through the direct and appropriate execution of field techniques (best practices through direct use of equipment and methods) and simultaneously allow significant progress in the detailed knowledge of the characteristics of groundwater in the subsoil of this sector of Bogotá, progressively also becoming a pilot laboratory for the advancement of the local hydrogeological knowledge, with country-scale projections for the training of hydrogeology professionals who contribute to closing the knowledge gap in the territory of Colombia..

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# Exploring the Impact of Artificial Intelligence as a Guide for Students during Assessment

Oumeima Ibn Elfekih[1], Maroua Douiri[1]

[1] Esprit School of Engineering, Tunis, Tunisia

Email: maroua.douiri@esprit.tn, oumeima.ibnelfekih@esprit.tn

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**Abstract**

This Artificial intelligence (AI) is a rapidly growing field of technology that has the potential to transform every aspect of our social interactions. In education, AI is beginning to generate new teaching and learning solutions, which are currently being tested in a variety of contexts. And if we apply AI in student assessments as a guide for them to understand more effectively the exam format and instructions, we can use the custom GPT. This article highlights the impact of critical integration of AI into learner assessment and focuses on the role of AI as a companion to assessment. By exploring the possibilities offered by customised GPT, we aim to demonstrate the impact and the potential of AI to transform the assessment experience for students. In this paper, we discuss the implementation of this method, its impacts on the learner, and provide recommendations to improve limitations for better future results. Our study results indicate that AI-assisted assessments significantly enhance students' understanding of exam formats and instructions, leading to improved academic performance. Survey data also shows a positive perception among students, with most finding AI assistance more beneficial than traditional methods. However, some challenges were identified, highlighting areas for further improvement. This study serves as a step towards achieving more effective integration of AI in learner assessments.

**Keywords**: Project Approaches; Learner's Evaluation; Artificial Intelligence; GPT; Custom GPT; Assessment experience.

## 1 Introduction

In recent decades, Artificial intelligence (AI) has undergone a huge evolution in many different fields such as medicine, manufacturing, transportation and education. In fact, AI is only a 60-year-old discipline that brings together science, theory, and technology particularly mathematical logic, statistics, probability, computational neurobiology, and computer science, and its purpose is about making machines perform cognitive functions to imitate humans (Sokolov and A 2019).

AI aims to enable machines to perform tasks using knowledge representations, reasoning modelling, text analysis and data extraction, and many other method (Zhang et al. 2021). It stands as a beacon of innovation, reshaping the way we approach learning and career development. In fact, the effective integration of AI skills into education requires a pedagogical framework.

Furthermore, while AI continues to advance at a staggering pace, the realisation of fully autonomous technologies, such as driverless vehicles, remains a distant prospect, highlighting the complex journey ahead.

The implementation of AI in education offers capabilities and potential to overcome many major challenges. It's bringing about a paradigm shift in education by providing revolutionary solutions to persistent problems and improving the quality of education.

Nowadays, emerging AI technologies have already been shown to have a positive impact on education, increasing learner engagement and motivation. The educational landscape is evolving profoundly, with innovation and adaptation driving the use of AI-powered solutions by both instructors and students. That's why they are massively using AI tools to support the learning and teaching process (Huang, Saleh, and Liu 2021).

Indeed, after the introduction of ChatGPT, from November 2021 to the present, we have seen an evolution in which the use of this ChatGPT increases, especially in learning (Montenegro-Rueda et al. 2023). This evolution demonstrates the growing reliance on ChatGPT as a valuable tool for knowledge acquisition and personal development. What's more, its integration with a variety of platforms and applications promotes its widespread adoption, making it more accessible and advantageous for users seeking knowledge and assistance.

Nevertheless, as our dependence on AI for learning support grows, questions about its application to learner assessment are raised (Hargreaves 2023). In fact, assessment in education plays a very important role in informing the various stakeholders about student progress, providing guidance for educational decisions, measuring effectiveness and encouraging student performance by validating learning achievements (Doğan et al. 1AD).

Indeed, students often find themselves in situations where they are assessed on one or more specific criteria as part of well-defined examinations. This pressure they feel during assessments can lead to considerable levels of stress. The latter varies according to the context of school assessments. Studies have shown that stress during examinations can lead to reduced performance and increased emotional tension (Tokaeva, Parshina, and Pavlenkovich 2012).This will affect the students' performance and put them in a situation where they won't fully understand the exam statement.

However, it's undeniable that the use of AI in exams does not benefit learners and can potentially harm their educational experience. Using AI tools during exams can increase the risks of cheating or breaching academic ethics. Students could use AI methods to access unapproved information, collaborate with their classmates, or manipulate evaluation results. AI algorithms can perpetuate existing prejudices and stereotypes, leading to unfair and inaccurate assessments of student performance (Panagopoulou, Parpoula, and Karpouzis 2023). Because of this, it is crucial to guarantee impartiality and justice in learner assessments, which necessitates a thorough analysis of the ethical issues related to the use of AI in educational assessment and, learner assessment should always be objective and open to everyone. As AI continues to advance in education, maintaining fairness and openness in student assessment remains an important consideration.

Considering that, the main objective of this article is how to integrate IA in learners' assessment exploring their role as a guide during examinations and to investigate its impact on students.

This integration was implemented in a continuous assessment test within a module called "Web Technology Project," dedicated to second-year students at ESPRIT, aiming to evaluate their ongoing progress effectively.

In this context, this paper examines the following research inquiry, how can AI be an effective tool for personalising academic advising? And how does this personalised approach underscore the importance of using AI in academic exams?

## 2 Description of the module

The course "Web Technology Project '' is an important six-credit module of the curriculum for second-year students common core IT students at ESPRIT School of engineering. The primary goal of this enlightening module is to provide students with the necessary skills to conceive, develop and execute a web-based technology project using HTML, PHP, and JavaScript languages. At the end of the course, students will have the capability to create a project in a group, elaborate on it, and recognize associated requirements. Additionally, they will have the capacity to collaborate efficiently in order to finish the project according to the timeline.

Evaluation of this module depends on two types of grades: assessments throughout the course and the project itself. The final grade is calculated by combining these two factors, with 30% for continuous assessment and 70% for the project evaluation.

This assessment method pays attention to students' comprehension of module concepts and their capacity to apply their knowledge.

# 3 Proposed Method

Assessments, which aim to measure students' skills and understanding, are crucial but can be hampered by problems such as unclear questions, complex situations and complex language. After the assessment of learning outcomes, we sometimes find that the majority of examinations that fail to produce good results are due to poorly posed questions, confusing problem scenarios or case studies using vocabulary that is difficult for some learners to understand. Unclear questions limit the ability to communicate understanding, while complicated subject areas such as mathematics or law make it difficult to put acquired ideas into practice. What's more, complex language poses a challenge, especially for students from diverse linguistic backgrounds. These obstacles act like linguistic landmines, unfairly disadvantaging some and obscuring the genuine learning achievements waiting to be revealed.

To ensure exams truly fulfil their purpose, students will need an assistant who can clarify the content of an exam without, of course, answering the question. As the teacher cannot be present on the day of the exam, it is important to put in place a system that enables students to benefit from guidance and support. So, students can get the help and support they need to assimilate the exam content without compromising the integrity of the assessment procedure. It enables students to manage their own learning process by providing them with the resources they need to succeed.

The use of an intelligent assistant (AI) is a solution as AI can provide students with personalised assistance. It can answer their questions in order to guide them in their thinking. Using an AI assistant for personalised assessment assistance can improve the learning experience by encouraging critical thinking, guided problem solving, and enhancing accessibility and inclusivity. By using AI, students are encouraged to analyse critically during assessments, examining the reasons behind their answers rather than simply repeating information. This encourages a better understanding of the topic and reinforces important analytical skills. In addition, Artificial Intelligence offers individualised guidance and recommendations to students when faced with complex assessments, acting as a valuable mentor. By helping students with complex problems and offering personalised support, AI helps them develop effective problem-solving strategies. What's more, AI encourages integration into the educational environment by offering assessment assistance to all students, whatever their requirements or position, ensuring the same opportunity for success for all learners. Fundamentally, incorporating these principles into the use of AI for assessment support improves academic performance and promotes the development of essential skills for lifelong learning and success. Moreover, AI can be used to ensure exam fairness. It can ensure that all students have access to the same information and support.

A promising pedagogical innovation is the use of intelligent assistance in the form of personalised chats on the GPT model during exams. This assistant can organise exam descriptions in the form of a knowledge database so that students can ask specific questions relating solely to the content of the exam. The assistant will not say that he or she will answer the questions on the exams, but will be an explanatory guide on how to answer the questions, explain the problem situations, etc... The AI assistant serves as a mentor to assist students in grasping concepts and finding solutions by offering guidance rather than direct answers. Providing immediate feedback enhances learning by enabling the instructor to correct students' misconceptions and steer them in the correct direction. Adaptive learning systems provide personalised assistance, as efforts to promote accessibility and inclusivity aim to enhance educational access (Wang et al. 2023) .Considering ethical principles is crucial, especially in upholding the integrity and confidentiality of exams. Teachers can establish a learning atmosphere that promotes in-depth comprehension, analytical thinking, and inclusive teaching methods through the use of intelligent support.

Teachers play an important role in the initial configuration of the wizard called Custom ChatGPT, defining parameters and limits and providing clear guidelines for its use. Advanced settings can include defining a limited number of questions that students are allowed to ask to encourage effective use of the assistant, as well as establishing guidelines for appropriate use. To ensure academic integrity, assistants may also be strictly forbidden from directly answering students' questions or accessing information on the Internet. The advantages of such intelligent assistance are manifold. It must be designed to be accessible to all levels of understanding and use simple, clear language. In addition, the interactive design of the assistant allows students to ask questions in real time, facilitating a dynamic learning environment. This encourages students' active participation in the consulting process and reinforces their understanding of key concepts. Finally, you can maximise its usefulness by customising your assistant to take account of your students' individual needs and preferences.

By adapting the explanations given to students to their specific level of understanding, assistants can play an important role in providing differentiated support to meet the diverse needs of the student population. And with the functionality of a custom version of ChatGPT that allows users to combine instructions, knowledge, and skills to customise it for specific tasks and topics, we can create an Exam Guide that can be the AI assistant for the student. The role of a custom GPT is to enable the creation of specialised, fine-tuned versions of the base GPT model. While creating it, you are asked to make some configuration and put restrictions for the student.

Below is an organigram outlining the method described:

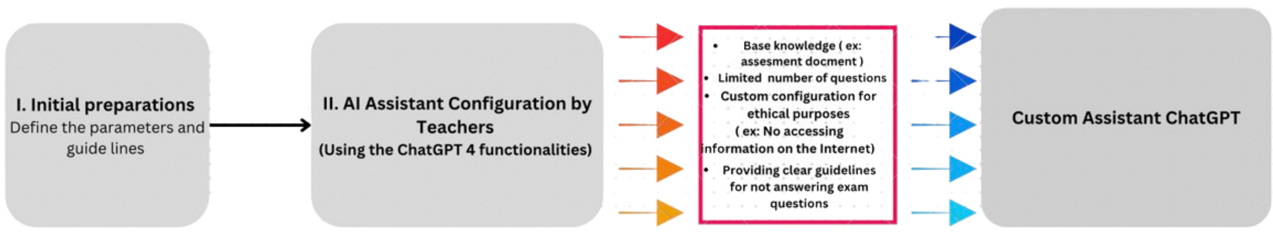


Figure 1. AI Assessment Guide Method

After creating the custom GPT we distribute it to the students for use during the web technologies project module test session. Students are permitted to utilise it throughout the duration of the exam.

## 4 Results

In previous sections, we have detailed the technique employed in our research, outlining the chosen approach in detail. By exploring in depth, we ensure an instructive journey through the results generated by this approach when put into practice.

Our investigation draws from two distinct yet interrelated streams of evidence: scholarly research and survey responses. By combining existing academic discourse and collecting first-hand data, our aim is to provide a balanced view of the effectiveness and implications of the guided exam custom ChatGPT.

## 4.1 Scholar Results

In Tunisia, learners are evaluated with scores ranging from 0 to 20. We utilized the proposed approach with 30 students to calculate the Continuous Assessment grade, which accounts for 30% of the overall average.

We compared scholar results using continuous monitoring grades from both the traditional and AI assistant approaches.

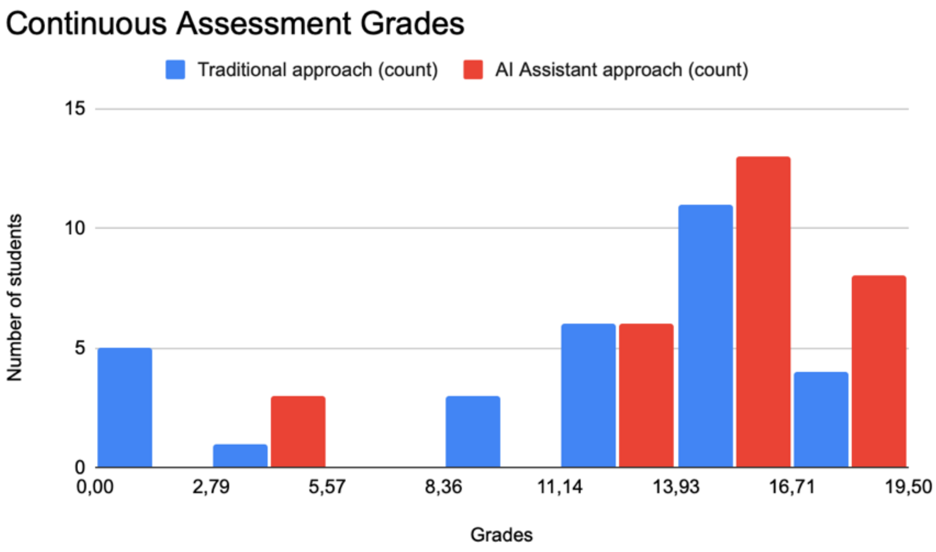


Figure 2. Histogram chart for Continuous Assessment grades

The histogram illustrates the distribution of student scores ranging from 0 to 20. Every bar shows the frequency of scores within specific intervals. When we compared the grades of continuous monitoring using traditional methods and AI assistant methods, we noticed a significant discrepancy. Using the suggested method led to a significant enhancement in academic performance, evident from a move towards better grades. This enhancement indicates that students could boost their grades by utilizing the suggested approach.

## 4.2 Survey Results

The survey included 5 questions about this experience (experiment). Questions with responses are listed here in Table 1.

Table 1: Overview of Student Feedback on AI Integration in Assessments,

| Question | Totally Disagree | Disagree | No opinion | Agree | Fully Agree |
|---|---|---|---|---|---|
| The AI-assisted assessment experience was more beneficial than traditional assessment methods. | 0% | 3,33 % | 13,33% | 26,67% | 56,67% |
| The use of AI in assessments significantly enhanced my understanding of the exam format and instructions. | 1% | 2,33 % | 10,33% | 38,45% | 47,89% |
| I encountered challenges or limitations while using the custom GPT for assessments. | 3,3% | 16,7% | 50% | 20% | 10% |
| Integrating AI into learner assessments should be further improved based on my experience. | 6,02% | 16,7% | 30% | 21,50% | 25,78% |
| I believe AI-assisted assessments should be integrated into more educational contexts to enhance the learning experience. | 1% | 3,33 % | 20,33% | 30% | 45,34% |

According to Table 1, we found out that the results of the survey show that the respondents have a mostly favourable view of AI-assisted assessments. Most people believe that AI helps improve the assessment process more than traditional methods do, with almost half saying that AI greatly improves their comprehension of exam formats and instructions. Nevertheless, a significant number faced difficulties or constraints when utilizing the tailored GPT for evaluations, indicating areas that could be enhanced. Participants showed a keen interest in improving and incorporating AI into student evaluations, acknowledging its ability to improve the learning process.

Overall, the results suggest a positive perception of AI-assisted assessments, with acknowledgment of both benefits and challenges. There is a clear indication of a desire for further improvement and integration of AI in educational settings.

For this reason, we decided to use the survey data to optimize our approach to integrating AI-assisted assessments in education. The findings highlight the need to overcome challenges, increase user satisfaction and preparing students for the future workforce emerged as key priorities. By embracing feedback, fostering innovation, and prioritizing ethical practices, educators can optimize AI's transformative impact on learning experiences.

# 5 Conclusion

In this paper, we presented our personalised method using custom ChatGPT as a guide in student assessments. The aim was to see whether this method can effectively replace actual teacher assistance during the exam, to enhance learning and provide useful information for students.

Research findings indicated that the use of personalized ChatGPT during assessments led to positive results. Students described a more beneficial assessment experience than conventional approaches, with significant advances in understanding of different exam types and instructions. In addition, the individualized assistance provided by the custom Chat contributed to a better assimilation of subjects and boosted overall academic performance.

Despite the promise of results, we are aware of the need for continued progress. Some modifications are required to improve the overall experience. This involves improving artificial intelligence algorithms to solve problems, improving user interfaces for an enhanced user experience and prioritizing ethical considerations when evaluating.

In conclusion, our study demonstrates the potential of guided exams as a valuable tool for assessing students, providing insight into its effectiveness and areas for improvement. By taking into account feedback and making modifications, we can apply this method in projects at ESPRIT as well, creating specific AI assistant for each module to further enhance the learning experience.

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# Active Learning, choosing the type of Resource according to Learning Style

Maroua Douiri[1], Oumeima Ibn Elfekih[1]

[1] Esprit School of Engineering, Tunis, Tunisia

Email: maroua.douiri@esprit.tn, oumeima.ibnelfekih@esprit.tn

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**Abstract**

The diversity of learning styles refers to the individuals' approach when it comes to receiving information. It can be described by the various ways individuals prefer to acquire and process information. Different educational resources have an impact on how students learn. This study examines how different types of resources can affect student learning. We're especially interested in understanding how visual, auditory, and written styles of learning are impacted. The idea is to make the learner an active participant in his learning by choosing the type of resource best suited to their preferred learning style. We applied a case study on 60 students studying the computer engineering diploma at the Esprit School of Engineering. The paper concludes with a discussion of how teaching based on different learning styles could be introduced into the school and the implications for teaching and assessment.

**Keywords**: Learning styles; Educational resources; Active learner; Computer engineering.

## 1 Introduction

Active learning is a paradigm shift in education that puts learners at the centre of the learning process. By actively engaging with course material, collaborating with peers and applying their knowledge to real-world situations, individuals develop the critical thinking skills, creativity and resilience needed to thrive in a changing world. Integrating active learning strategies tailored to different learning styles can increase the effectiveness of educational interventions.

The learner plays a central role in the learning process. In addition to the traditional role of the teacher, the learner is also a major player in his or her own acquisition of knowledge and skills. Understanding the learner's role in learning is essential to designing effective and stimulating learning environments (Liang et al.,2023).

Learners have different preferences about how they absorb information. Some learn best through hands-on, experiential activities, while others prefer verbal explanations or visual aids. By identifying each student's learning style, teachers can adapt their teaching methods to meet individual needs, promoting deeper understanding and better retention (Moneva et al., 2020).

The importance of learning style in a learner's education lies in its ability to influence the way an individual acquires, processes and retains information. Understanding learning styles enables educators to design teaching strategies that are appropriate for each learner, leading to better retention, greater motivation and a more positive learning experience. When learners are exposed to teaching methods that match their preferred style, they are more likely to actively engage in the learning process. This can increase their intrinsic motivation by building confidence in their abilities and creating a positive and stimulating learning environment (CB, 2022).

Learning style is the way in which each learner begins to concentrate on, process, absorb, and retain new and difficult information (Dunn and Burke, 2005). The interaction of these elements occurs differently in everyone. Therefore, it is necessary to determine what is most likely to trigger each student's concentration, how to maintain it, and how to respond to his or her natural processing style to produce long term memory and retention. To reveal these natural tendencies and styles, it is important to use a comprehensive model of learning style that identifies each individual's strengths and preferences across the full spectrum of physiological, sociological, psychological, emotional, and environmental elements. (Pashler et al., 2009).

The learning styles will certainly differ among students in the classroom; Dunn and Dunn said that teachers should try to make changes in their classroom that will be beneficial to every learning style. Some of these changes include room redesign, the development of small-group techniques, and the development of Contract Activity Packages. Redesigning the classroom involves locating dividers that can be used to arrange the room creatively, clearing the floor area, and incorporating student thoughts and ideas into the design of the classroom (Dunn et al., 1979).

Over the years several theories and types of learning style models have been developed. The learning style has several models pioneered by some of the people figures. Among the models of learning styles are such as Dunn and Dunn learning style model, Kolb learning style model, Felder Silverman learning style model, VAK learning style model, Visual, Audio, 'Read and Write' and Kinesthetic (VARK) learning style model, Honey and Mumford learning style model, Selmes learning style model and so on. (Kannan et al., 2011).

In comparison to other learning modes, the VARK model is more sophisticated and provides more desirable outcomes. Its purpose is to examine the relationship between the mind and linguistics in an individual's behaviour (Hawk et al., 2007). The VARK learning style model, introduced by Fleming, is a questionnaire that identifies a person's sensory modality preference when learning. This model classifies students into four different learning modes: visual (V), auditory (or Aural)(A), read/write (R) and kinesthetic (K).

While there are several tools to study learning styles of students, the visual-aural-read/write-kinesthetic (VARK) questionnaire is a simple, freely available, easy to administer tool that encourages students to describe their behavior in a manner they can identify with and accept. The aim is to understand the preferred sensory modality (or modalities) of students for learning. (Urval et al., 2014).

The aim of this paper is to explore how we used the VARK model to identify how students prefer to learn in different activities. Through our own experience, we have gained valuable insights into the impact of this approach on learners.

# 2 Methodology

## 2.1 Description of the module

It is a three-credit module which consists of an integrated course entitled service-oriented architecture SOA.

It is taught during the first semester of each academic year. The former is extended for 7 weeks, and 9 hours asynchronous activities. This module is intended for 2nd year Computer Engineering whose number is approximately 570 divided into 9 specialities. In software engineering, service-oriented architecture (SOA) is an architectural style that focuses on discrete services instead of a monolithic design. Students are required to understand this architectural style and implement a REST API in order to meet the requirements of their final client. Teachers prepare a Moodle space related to this module where learners can find all the necessary tools and resources. Teachers upload assignments for students to complete and add a discussion forum for further interaction in addition to other useful links.

## 2.2 Description of the approach

This section is a detailed description of the strategy we have in place to put our experience into practice.

This task involved four steps:

(a) preparing the VARK questionnaire (in Google Forms)
(b) sending the form's link to be completed by learner
(c) analysing the results of the questionnaire
(d) Identify the learning style of each individual learner to determine what forms of evidence would be needed to justify basing pedagogical choices on materiel resource of students' learning styles

The module average is calculated as follows: Average = 20% Continuous Monitoring (CM) + 80% Final Examen

In this experience, we choose two different activities and we contribute the score in CM. There were two activities:

1. The first activity is based on an individual exercise for which we have (as a teacher) provided teaching resources (statements, lessons, explanations, etc.) according to the learning style of each student, as identified during the analysis of the completed forms.
2. The second activity is a team activity. Normally, teams are formed at random, but this time we selected teams based on learning style results. Students with similar learning styles are grouped into teams of 5 or 6 students.

The first activity is on chapter 2 introduction and discussion of the engineering SOA architecture and we have provided an exercise to do and resources to consult to give us an explanatory affinity.

The second activity is based on chapter 3 introduction and discussion of the engineering REST architecture, and is based on a problem-based learning (PBL). We (as a teacher ) have provided all the necessary resources to consult and to give us an explanatory affinity with executable code according to the given statement.https://orbi.uliege.be/bitstream/2268/296618/1/1998 Leclercq Van der Vleuten PBL PPUQ Chap8.pdf

VARK Model in Teaching use 4 types of learning style as shown in the figure below:

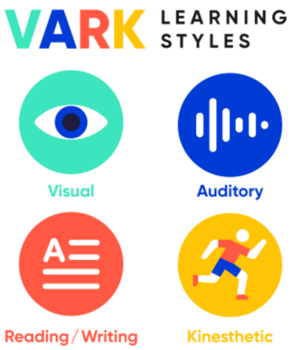


Figure 1. VARK Learning Styles

1. One style of learning is visual. People whose dominant learning styles revolve around visual stimulation. They strongly prefer to process and understand information using visual aids like charts, diagrams, graphs, pictures and videos. (Kumah et al., 2022). For this category, we provided the resources in the form of capsules (videos)and pictures.
2. For auditory learners, listening is the preferred method of learning. They tend to absorb and retain information presented in an auditory format more effectively. This is why participation in group lessons, exercises and discussions is so important to the learning process. (Kumah et al., 2022)
For the auditory learning style, we provided all the resources in the form of audio (recorded lectures and podcasts (mp4)).

3. For reading/writing learners (or Literate learners), also known as oral language learners, prefer to learn through the written word and text-based materials. They have an excellent affinity for reading, writing and using written information. (Kumah et al., 2022)
   For the reading/writing learning style, we provided all the resources in the form of documents (books, article, word, pdf, paper and online resources)
4. Kinesthetic learners can be identified using a number of observable characteristics. These learners tend to be very active and prefer hands-on experience. They find it difficult to stand still for long periods and tend to move around frequently. Kinesthetic learners also have a strong inner voice of their own body and are able to make physical gestures and movements when thinking and speaking. (Kumah et al., 2022)
   For the kinesthetics learning style, we provided all the resources in the form of role-playing, experiments, and simulation.

In this part, we had a difficulty in preparing resources according to learning style preferences. It was essential to research the preference of each style before preparing the resources. All the resources were shared using the standard drive tool.

This study was conducted at the beginning of the first semester of the 2023/2024 academic year. Quantitative measures were used. We only carried out our experiment on two classes, and around 60 students took part in our survey. Students were asked for feedback using paper surveys. The survey was anonymous. We received 56 responses from 60 registered students. This represents a participation rate of approximately 93%. The ages of participants range from 21 to 25 with the age of 22 approximately.

# 3 Results

## 3.1 Scholar Results

We only carried out our experiment on two classes (60 students). For data collection, the VARK questionnaire was adopted and used. Descriptively, it was noted that 24(40%) of the participants prefer Visual learning ,23 (38%) are Kinesthetic learning ,7(12%) prefer Auditory learning , and 6(10%) prefer Reading/Writing learning style. Preferred student's learning style are shown in Fig. 2.

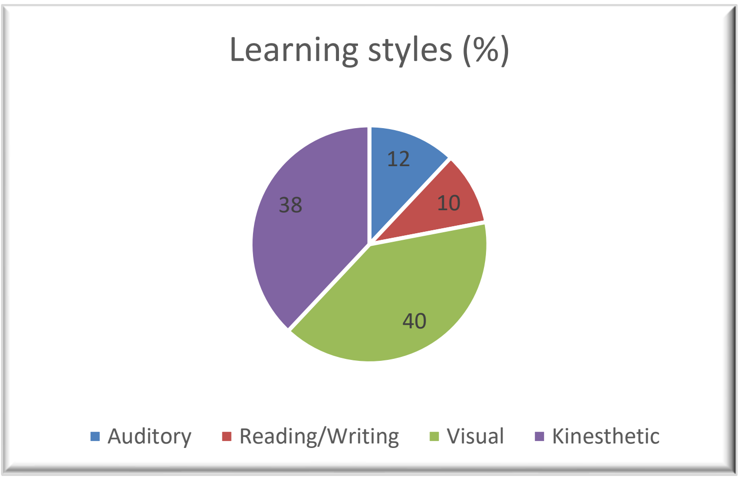


Figure 2. Learning styles by percent

On the other hand, we have noticed that the distribution of preferences according to gender is as follows in Table 1

Table 1. Male and Female Students' Learning Styles.

| Gender/Learning Styles | Number | Auditory | Visual | Reading/Writing | Kinesthetic |
|---|---|---|---|---|---|
| **Male** | 24 (40%) | 8,03% | 24,8% | 5,30% | 64,44% |
| Female | 36 (60%) | 12,54% | 75,20% | 9,80% | 35,56% |

The number of students per interval of their averages (CM) shown in Fig. 3. This figure shows that

about 97% of the students validated their activities. Compared to the traditional method of the previous year, this percentage is more interesting.

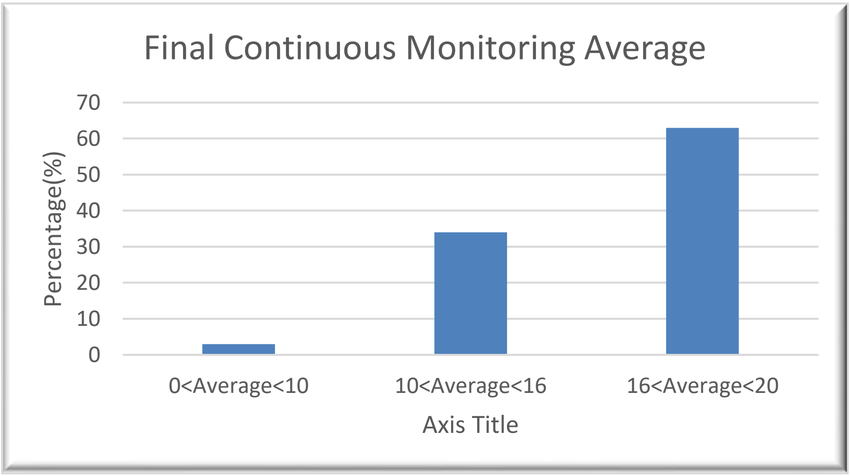


Figure 3. Final Continuous Monitoring Average

Table 2. Results of participations.

| Activity | First Activity (Individual) | Second Activity (Group) |
|---|---|---|
| Download resources | 87% | 75% |
| Workshop submission on Moodle | 97% | 93% |
| Students who validate the workshop | 97% | 93% |

Table 2 shows that 97% completed the first activity, 93% submitted the second activity. Table 2 also shows the number of students who download their resources. In the second activity, we had the observation that only one or two learners had downloaded the resources for the whole team.

It shows also the number of students that validated their workshop (activity 1 and 2) and they obtained at least 10/20. Finally, 97% of students validated the first activity, 93% of students validated the second activity.

## 3.2 Survey Results

The survey included 8 open-ended questions about this experience (experiment). Questions with responses (anonymous) are listed here in Table 3

Table 3. Overall Satisfaction.

| Question | Totally Disagree | Disagree | No opinion | Agree | Fully Agree |
|---|---|---|---|---|---|
| The final mark reflects your work done | 8,03% | 19,20% | 5,30% | 22,44% | 44,70% |
| The VARK Questionnaire was a good experience in PBL | 12,54% | 15,65% | 9,80% | 16,78% | 45,23% |
| Teachers' assessment is more reliable | 15,67% | 51,61% | 8,93% | 12,45% | 11,34% |
| I feel that I can do better next time | 7,38% | 2,57% | 10,58% | 32,06% | 45,20% |
| The rules and steps of the workshops have been clearly explained by your teacher | 7,82% | 12,01% | 9,23% | 11,81% | 40,87% |
| Are you satisfied with the results of your preferred learning style? | 8,03% | 16,06% | 4,23% | 45,81% | 25,87% |
| Did you enjoy the experience? | 3,04% | 10,58% | 4,27% | 15,81% | 66,33% |

According to Table 3, we found out that about 81% are satisfied this experience. 45% are totally agree with the VARK experience in PBL. Only 70% said that they agree with the result of VARK questionnaire and 66% are satisfied with their final marks. Only 51% think that the rules and instructions were clear.

We list below some comments extracted from our survey:

"We're glad to have experienced this"

"Further tutorials and details about work needed"

"Dispose more clear videos with explanation, more explanations from my tutor"

"Keep our team with a selected learning style in case of randomness, I enjoyed this experience"

"I think that we must apply the Vark model of learning style in all of our courses and project"

As it was our first experience, we can understand the different opinions of several students. For next year, we have a number of things in mind in order to improve this experience. We propose to plan more training sessions for our team of tutors, to have some videos on Moodle to explain each stage, whether in each activity. The course materials available on Moodle should also be improved.

The survey showed that students can be encouraged to reflect critically on their own learning and performance by tailoring course materials to take account of their learning styles. It also helps them become more aware of their weaknesses and strengths.

# 4 Discussions

When we visualise the work of a team on a problem situation in which they are divided according to the nature of their learning style, we have noticed the following points:

Visual learners: They take notes, underline or highlight key points and sketch during lectures or discussions.

Auditory learners (Aural): Class discussions and verbal activities are enjoyed by auditory learners.

Reading and Writing learners: they highlight key points, taking notes, and summarize information which helps them process and retain the material;

Kinesthetic Learners: they enjoy the practical examples or stimulations. It is more difficult for them to grasp a theoretical situation or an abstract concept.

On the other hand, we have noticed that the distribution of preferences according to gender is as follows in Table 1 so the learning style is influenced by gender factor. Kinesthetic is the most influential learning style for male students, while for female, visual is the most significant learning style.

# 5 Conclusion

The term learning styles refers to the view that different people learn information in different ways. Understanding different learning styles and using the VARK model can greatly improve the effectiveness of your teaching. By recognising and responding to the different learning preferences of your students, you can create inclusive and engaging learning environments that promote meaningful understanding and retention of content. Every student has these different learning preferences, so it's important to take them into account to unlock their potential. The appropriate learning style model can help students to learn and understand learning approach, help to enhance self-strength and identify situations that can help towards the effectiveness of learning (Morrow, 2011). Understanding a good learning style has a number of positive effects for both teachers and students. A good understanding of a learning style will enable the teacher to explain the learning strategies that appeal to students according to their preferences. Teachers, in turn, can plan and implement appropriate teaching strategies in a way that students can easily understand. Teachers can play a role in helping pupils to explore learning strategies that suit them and are effective for them.

While the results are encouraging, we are of the opinion that some adjustments should be made in order to improve the overall experience. We will discuss the hybrid learning styles in the next step. We may find students who are both auditory and kinaesthetic, and others who are both visual and kinaesthetic, etc. This point will be explored in a future paper.

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# Challenges of Teaching a Hands-on Virtual Reality Course


Pedro Emil Freme, Luciano P. Soares

Insper Instituto de Ensino e Pesquisa, São Paulo, Brazil

Email: pedrohepf@insper.edu.br, lpsoares@insper.edu.br



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**Abstract**

Virtual reality, within the realm of computer engineering, possesses a rich historical legacy dating back to the emergence of the first virtual reality headsets in the 1960s. Today, the field has matured significantly, boosting highly sophisticated hardware and software capable of rendering complex 3D simulations. However, teaching virtual reality presents a formidable challenge due to the relentless pace of technological evolution. With new tools and standards emerging regularly, educators face the daunting task of maintaining up-to-date instructional strategies. Traditional teaching resources, such as books, often fall short, particularly in hands-on virtual reality courses, where the techniques for implementing user experiences are in a constant state of flux. Even theoretical content within textbooks may become swiftly outdated, making certain optimizations obsolete as new strategies emerge with remarkable frequency. In this paper, the process of identifying a foundational knowledge base for virtual reality that is less susceptible to obsolescence is elucidated. Strategies for curating and preparing instructional materials for students and offer support mechanisms to address information gaps will be outlined. Despite the rapid evolution of the field, students can successfully engage in the development of sophisticated projects within the realm of virtual reality.



**Keywords**: Teaching Challenges; Instructional Strategies; Virtual Reality Evolution.


## 1 Introduction

Since Ivan Sutherland's pioneering contributions to Virtual Reality (VR) in the late 1960s, the field has remained specialized, with few available devices, usually expensive, a small community, and a limited set of standards. However, in the 2010s, Palmer Luckey founded Oculus, introducing a product that was an immediate success: the Rift headset (Tribe & Dr. Sivarethinamohan, 2023). This innovation marked the beginning of a VR revolution, catalyzing the entry of immersive technologies into consumer markets, transforming them into commodity products rather than something only affordable by large companies or research centers, and fueling the growth of what is now a multi-billion-dollar industry (*AR & VR - Worldwide | Statista Market Forecast*, n.d.).

The rapid advancement of virtual reality (VR) technology presents a formidable challenge for educators in this area, relying on traditional educational resources like textbooks, slide presentations, and video content. With an array of vendors, alongside diverse content creation tools including Unity, Godot, Unreal, and various native software development kits (SDKs), the landscape of VR technology is both vast and intricate. These continuous and swift technological evolutions necessitate regular updates to course materials, which struggle to align with the latest software and hardware developments. Educators must navigate this complex ecosystem to effectively incorporate new techniques, optimizations, and solutions into their curriculum, ensuring that their teaching methods are both updated and relevant.

Dynamic course material is proposed to establish a foundational knowledge base in virtual reality (VR) that remains resilient amid rapid technological changes. This course not only introduces essential VR concepts and techniques but also incorporates adaptive learning strategies to continuously integrate the latest advancements in the field, ensuring that students are always at the forefront of VR technology. The use of community resources and artificial intelligence tools is also explored to support and enrich the learning process. Furthermore, the creation of a dynamic learning environment is emphasized, which encourages students not only to acquire knowledge but also to engage in continuous learning and share their experiences. This approach fosters a collaborative and adaptive educational ecosystem.

In the following sections, there is a discussion on the establishment of development environments for virtual reality, with a detailed curriculum. The paper concludes with our observations, highlighting key insights and outcomes derived from the implementation of these educational strategies.

## 2 Development Environment for Virtual Reality

Access to VR equipment is crucial in a student's learning journey in modern VR technology. Many traditional VR courses fall short by focusing solely on the theoretical aspects of Virtual Reality as a mere topic in computer graphics (Häfner et al., 2013). This approach can significantly hinder a comprehensive understanding of VR technologies, since it is a complex area, that involves from hardware to software, from programming to designing experiences. Hands-on experience is essential for grasping the complex interplay between software and hardware that VR entails. Ensuring students have the necessary tools to engage directly with VR environments is key to fostering a deeper, more practical mastery of the subject. This document presents the experience of a laboratory, in which VR-ready workstations are provided equipped with Head-Mounted Displays (HMD) to facilitate this endeavor.

For the HMDs, the HTC Vive, a PCVR system (Personal Computer Virtual Reality system) that connects a PC workstation to a Virtual Reality device, was initially utilized. This device was developed through a partnership between Valve and HTC, and launched in 2016 (Lomas, 2016). As a robust PCVR system, the Vive headset must be connected to a computer, typically via cable. While wireless options also exist, they significantly increase the setup's complexity, cost, and add dependencies on additional software and hardware. The reliance on a computer's processing power enables high-performance VR experiences but also introduces potential points of failure in the connections. This often leads to technical issues that require extensive troubleshooting. To overcome the difficulties in both efficiency and reliability, the HTC Vive headsets were upgraded to Meta Quest 2, a standalone VR system. Unlike the PCVR systems, the Meta Quest 2 has a single USB cable for connecting with a PC but can also be connected through conventional Wi-Fi infrastructure. Meta Quest also works without a connection to a computer, which simplifies the setup even more and reduces potential technical issues. This newer system has proven significantly simpler and more user-friendly, greatly improving the accessibility and quality of student projects. Its integrated processing capabilities allow for a seamless VR experience, free from the cumbersome wires and additional hardware requirements of traditional PCVR setups. Figure 1 shows the two virtual reality kits. Notice that the HTC Vive has a larger number of cables and depends on active infrared patterns that must be strategically positioned on the environment, while the Quest 2 is much simpler.

To ensure the students' activities and projects progress smoothly during the academic semester, it is crucial that students have flexibility to access VR equipment, allowing student's access throughout the day, as well as support provided by a laboratory technician. These technicians do more than just oversee the use of the lab, they bring expertise in Virtual Reality development and are readily available to assist students technically. This not only enhances the students' development process but also ensures a seamless and productive learning experience. Their support is vital in helping students overcome technical challenges and in fostering an environment conducive to innovation and learning.

Since this course's inception in the laboratory, back in 2017, a variety of tools and platforms in virtual reality development were actively explored. Initially, the toolkits presented for students included VRTK (VRTK, 2024), an open-source project designed for cross-platform VR development. However, its utility has been diminished over the years. The following main toolkit presented for developing VR project was then Valve's SteamVR, which, despite its potential, posed increasing challenges due to a lack of comprehensive documentation (Valve, 2024), thereby negatively impacting the learning experience.

Figure 1. Comparison between HTC Vive and Meta Quest 2 Virtual Reality Kits

In response to these challenges, the latest iteration of the course has transitioned to using Unity native XR Interaction Toolkit (XRI) platform (Unity, 2024), with OpenXR development environment (Khronos, 2024), but also the Meta Interaction SDK (Oculus Developers, 2024) for some specific needs. The OpenXR is usually selected for its robust features, extensive support for a wide range of VR hardware, and a growing community that provides well-maintained documentation. Furthermore, understanding the importance of diverse skill sets and personal interests, students are encouraged to explore and choose alternative tools such as Godot or Unreal Engine. This flexible approach not only enhances their technical proficiency but also allows students to customize their learning experience to align with their future career goals or personal interests in VR development.

## 3 Ensuring Foundational Learning

One of the first challenges in virtual reality (VR) education is that traditional teaching resources, such as textbooks and lecture materials, often struggle to keep pace with the rapid evolution of VR technology. This discrepancy can lead to significant gaps in students' understanding and proficiency, undermining their ability to adapt to innovative technologies, a skill essential for success in the field.

To address these challenges, community-generated content was incorporated into course material, including freely available videos, official and unofficial tutorials, and forum threads. By actively curating these resources, a rapid iteration and timely updates to our course content is maintained. This strategy not only keeps our course material aligned with the latest developments in VR but also cultivates a lifelong learning mindset among students. Such an approach is critical in preparing them for the continual challenges and opportunities they will encounter throughout their careers. In the latest version of this course, a sequence of videos from the YouTuber Valem was used (Valem, 2024). While some educators might criticize this method, the fact is that students can follow the instructions while simultaneously understanding technical concepts. Students are much more comfortable watching videos to learn the practical aspects of virtual reality and the tools used. Although written material is also provided to explain the tools, students were more effective when using videos.

Furthermore, it is essential to look beyond the practical implementation of virtual reality experiences to address the foundational building blocks of the technology and its context. The proposed curriculum, therefore, includes a range of fundamental topics such as types of tracking, stereoscopy techniques, and other core theoretical principles. These lectures are designed to ensure that students not only understand but also connect with the VR frameworks. For an overview of these lectures and their specific content, please refer to Table 1.

Finally, when examined the definition of a Virtual Reality (VR) experience, it aligns closely with the well-known framework of the '3I's': Immersion, Interaction, and Imagination. Immersion provides users with a convincing, all-encompassing virtual environment that often transcends physical reality. Interaction allows users to manipulate and engage with this environment in intuitive ways, further enhancing the sense of presence within the virtual world. Lastly, Imagination powers the creation and expansion of these environments, pushing the boundaries of what is possible and enabling experiences that are not feasible in the physical world. Together, these elements form the core of what makes VR a uniquely transformative technology (Burdea & Coiffet, 2003).

To facilitate this learning progression, the implemented VR course is structured around three progressive projects, each one designed to deepen students understanding and skills within the realms of both virtual and augmented realities. These projects incrementally build on each other, ensuring that with each step, students are better prepared to work in the intricate demands of VR and AR technologies.

The proposed learning path is inspired in the Challenge-Based Learning (CBL) approach, where in this case a progressive path of knowledge acquisition in VR development is established, ensuring that students achieve a comprehensive understanding of core virtual reality topics. This method promotes active problem-solving and real-world application, allowing learners to deeply engage with the material while developing critical thinking skills. As they progress through increasingly complex challenges, students not only solidify their grasp of foundational principles but also enhance their ability to creatively apply this knowledge in diverse scenarios.

Table 1. Planned classes for Virtual Reality Course.

| Class # | Content | Discussion |
|---|---|---|
| 1 | Experience in Virtual Reality | Familiarization with Virtual Reality devices, XR Discussion |
| 2 | Developing for Virtual Reality | Familiarize with the headsets, and start the first project |
| | Project 1: Escape Room | |
| 3 | Introduction to Virtual Reality | An overall of the basic aspects of Virtual Reality |
| 4 | Head-Mounted-Display | Main details of the modern Virtual Reality headsets |
| 5 | Sensor Tracking | Tracking system and integrations in virtual environments |
| 6 | Development Standards | Main standards for Virtual Reality development |
| 7 | Depth and Perception | Stereoscopy, Binocular disparity, Field of View |
| 8 | Virtual Reality Applications | Areas where virtual reality has supported users |
| 9 | Experience Design | Design strategies to create a better experience |
| | Project 2: AR Project | |
| 10 | Augmented Reality | Operation of Augmented Reality Systems |
| 11 | Forms of 3D Interaction | Interaction devices, force return |
| 12 | Virtual Menus | Discussions on forms of virtual menus, Heads Up Displays |
| 13 | 3D Physical Simulations | Interaction Issues, Particles, Ray Casting |
| 14 | Avatars | Kinematics Inverse, Deformable Meshes, Animations |
| 15 | Studio Class | Project Development |
| 16 | Spatialized 3D Audio | Development of scenarios with spatialized audio |
| | Project 3: Final Project | |
| 17 | Metaverse | How to participate in virtual environments |
| 18 | Distributed Virtual Environments | How to synchronize distributed content |
| 19 | Skybox and 360 Degree Photos | 360-degree media captures |
| 20 | Data Entry System | Eye-tracking, Leap-motion, Virtual Reality Gloves |
| 21 | Level of Detail Control | Include Level of Detail Control (LOD) |
| 22 | Locomotion | Teleportation and tracked displacement systems |
| 23 | 3D Modeling | 3D modeling shapes and tools |
| 24 | Phasic System | Return of force, vibrations |
| 25 | Publishing WEB VRML/X3D | Presentation of x3d format for web. |
| 26 | 3D tracking by cameras | Capture position and movement by camera systems |
| 27 | Final Demo | Final Demo |

## 3.1 Projects

### 3.1.1 Escape Room

The first course project serves as an introduction to virtual reality, challenging students to create their own Escape Room game (Figure 2). Escape room games are highly popular in VR, comprising interactive puzzle environments where players are 'locked' in a room or a series of rooms. To progress and ultimately escape, players must meticulously explore their surroundings, gather distinct items, and solve a sequence of puzzles using clues from the environment. This genre effectively leverages the immersive capabilities of virtual reality to enhance problem-solving experiences, deeply engaging students and making them feel an integral part of the complex scenarios they develop.

Despite its perceived simplicity, this project introduces several fundamental concepts critical to virtual reality applications. It illuminates discussions on environment scale and perception, the clarity of interactive elements, and the use of spatial, diegetic, and non-diegetic 3D user interfaces. Moreover, it explores various techniques of player movement, such as teleportation, among others. This project not only teaches technical skills but also fosters a deeper understanding of how VR environment's function and how they influence user interaction.

Figure 2. Escape Room Projects made by the students[1]

### 3.1.2 AR Project.

In the second project, the focus shifts to augmented reality (AR), enabling students to explore a different technology within the extended reality (XR) spectrum. This project introduces multiple AR techniques, such as marker tracking with ARUco markers (Garrido-Jurado et al., 2016), other marker systems, markerless techniques, and geospatial markers. Advanced topics like simultaneous localization and mapping (SLAM) (Gaia et al, 2023), image recognition, and the integration of AR with IoT devices are also covered, providing a broad view of AR's versatility and practical applications.

Students are not required to use specific technology, however, they commonly select the Vuforia Engine (PTC, 2024), a widely used augmented reality software development kit known for its user-friendly interface and rapid results. Vuforia's advanced computer vision capabilities allow for the real-time recognition and tracking of images and objects, making it an ideal choice for developers seeking to create immersive and interactive AR experiences efficiently. This technology supports students in quickly transitioning from concept to execution,

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[1] Top Left: https://gubebra.itch.io/hypostatize Top Right: https://lidiaacd.itch.io/orbsescape
Bottom Left: https://mikomoares.itch.io/horizontal-tower Bottom Right: https://siredington.itch.io/escape-alien

significantly enhancing their learning process through practical application. Overall, this project is designed to familiarize students with AR's unique characteristics and potential applications, encouraging them to explore how AR technology can be seamlessly integrated into real-world scenarios and thus broadening their technical repertoire (Figure 3).

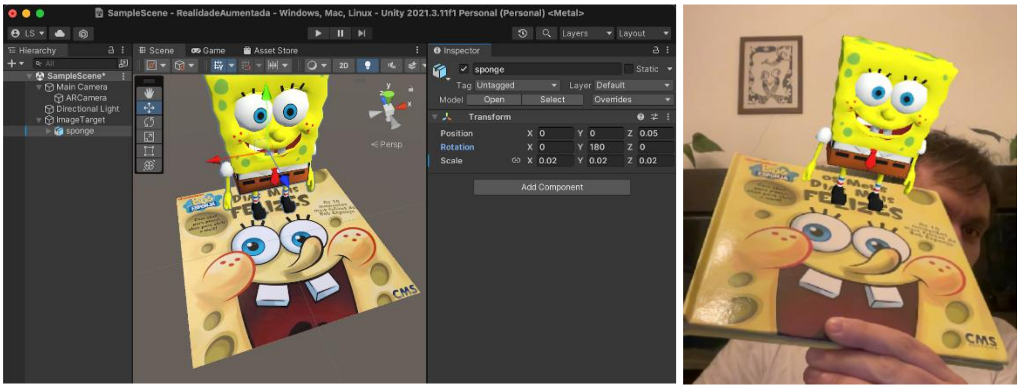

Figure 3. Augmented Reality project with image as marker

### 3.1.3 Final Project

The final project in our curriculum grants students the autonomy to fully apply the breadth of knowledge they have acquired throughout the course. In this project, students are tasked with defining a unique theme that serves as the foundation for their virtual reality (VR) creation (Figure 4). They then engage in a weekly scrum-based (Jurado-Navas, 2017) approach, which facilitates iterative planning, development, and refinement phases, mimicking real-world software development cycles. This method not only reinforces project management and teamwork skills but also helps students stay aligned with their project goals and timelines.

As they progress, students are required to draw upon their full range of VR development skills, from conceptualizing the initial idea to implementing and refining the final product. This phase of the course is critical as it challenges them to synthesize and apply everything they have learned in a practical setting. They must navigate the complexities of VR design, including user interaction, environmental design, and the integration of advanced VR features to create compelling, immersive experiences. By the end of this project, students are expected to deliver a complete VR experience, demonstrating their competence and innovation in crafting engaging virtual environments that are both functional and imaginative.

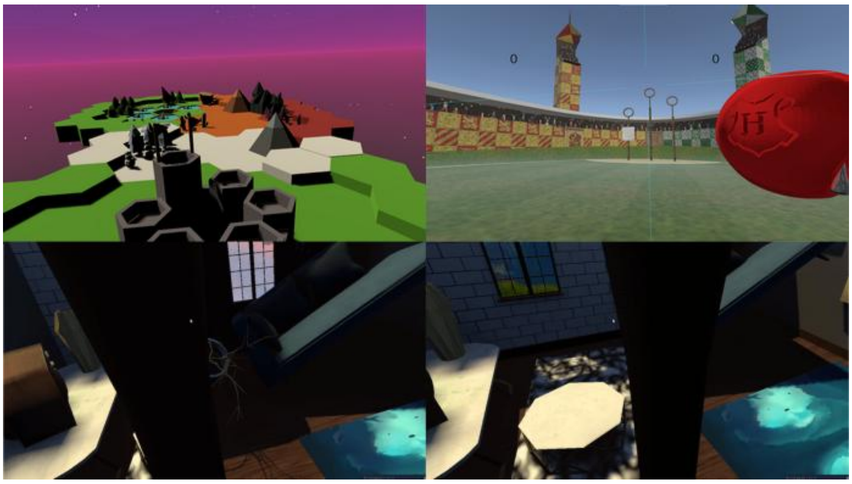

Figure 4. Final Projects made by students[2]

[2] Top Left: https://anaclaracf.itch.io/mini-golf-vr Top Right: https://sirjohnwilliam.itch.io/quiddich-harry Bottom: https://gubebra.itch.io/mirage

## 3.2 The Metaverse Experience

Defining the Metaverse remains a challenging endeavor in today's rapidly evolving topic (Ritterbusch, 2023). By defining the metaverse as a collective virtual shared space which is persistent and online that facilitates continuous and seamless interactions among users within a computer-generated environment. Our course focused on the available metaverse platforms on the market.

In addition to the core projects, previous versions of the course included a fourth project aimed at applying the skills developed to create an experience within the Metaverse. However, this project was discontinued due to several challenges, particularly related to platform selection. Among the platforms considered was Meta Horizons, a well-known but closed platform for content creators at the time of our evaluation. Another potential platform, VRChat, while popular, requires creators to earn 'trust' through prolonged engagement (VRChat, 2024), which was impractical for a time-bound academic project. Microsoft's AltspaceVR was another viable option until its discontinuation in early 2024 (AltspaceVR Team, 2023). Lastly, NEOS VR was evaluated but found to be too unstable for our needs. Due to these complications, it was decided to focus on the final project, which allows for a broader application of VR development skills without the constraints of existing Metaverse platforms.

Figure 5: Project of virtual environment in the AltspaceVR platform

# 4 Results and Observations

The emphasis on hands-on experience with a variety of VR systems has been crucial in deepening students' understanding of VR technology. By engaging directly with advanced tools and platforms, students gain a comprehensive appreciation of the complex technologies that underpin modern VR systems. This exposure not only fosters a deeper understanding but also encourages innovation within this rapidly evolving field. Moreover, by transitioning to more reliable VR hardware like Meta Quest 2 and streamlining the development environments, the frequency and severity of hardware-related disruptions was significantly reduced. This update to standalone VR systems has not only decreased the time students spend troubleshooting technical issues but also enhanced their ability to maintain a steady workflow. As a result, students can focus more on developing complex and high-quality projects, leading to the creation of richer, more engaging VR experiences. The seamless integration of these systems into our course framework allows creativity and technical skills to flourish, underscoring our commitment to providing a robust educational experience unimpeded by technical malfunctions.

These observations collectively highlight how improvements in VR equipment access and system reliability have not only enriched the learning environment but also broadened the scope of what students can achieve. As a result, students get well-prepared to lead and innovate in the field of virtual reality, equipped with both a solid understanding of technology and the capability to apply their skills in complex, real-world scenarios.

# 5 Conclusion

The field of virtual reality is evolving at an unprecedented pace, what makes necessary to rebuild the practical activities material, every semester, making the task of keeping in level with daily updates and changes akin to the labors of Sisyphus. The industry is entering an era where Virtual Reality technology is beginning to stabilize, marked by developments such as the evolution of the OpenXR standard, which reflects the maturing nature of the medium. By immersing students in the fundamental concepts of virtual reality and encouraging them to freely explore various tools and ideas, fostering an educational environment that not only facilitates interaction with innovative technology but also enhances learning through experiential engagement. This approach cultivates the essential skill of 'learning to learn,' empowering students to adapt and thrive in dynamic technological landscapes.

The word 'challenge' was used in several contexts in this paper. The first is the challenge of keeping a virtual reality course updated amidst the constant evolution of the field. Although Challenge-Based Learning (CBL) is not the focus of this paper, this is a strategy employed in some projects to motivate students to learn a new area or topic by posing a challenge they must overcome. Finally, students were motivated to create applications, usually games, that present real challenges for their end users, the players. In summary, Virtual Reality poses numerous challenges.

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# Student Inclusion as an Institutional Focus: Report and Implementation of Support Strategies for Educating a Visually Impaired Student in an Engineering Program

Luana Thereza Nesi de Mello[1], Rafael Hauckewitz Todaro[2], Ana Cristina Caldeira[1], Cristiane Maria Barra da Matta[3], Guilherme Wolf Lebrão[4]

[1,2,3,4] Mauá Institute of Technology, São Caetano do Sul-SP, Brazil.

Email: apoio.aluno@maua.br, rafael.todaro@maua.br, cristianebarra@maua.br, guinet@maua.br

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**Abstract**

The inclusion practice in universities is a crucial aspect of enriching the academic experience for all students, regardless of their backgrounds, abilities, or individual characteristics. In this context, this article reports on the inclusion experience of a visually impaired student in an Engineering program at the Mauá Institute of Technology, highlighting the psycho-pedagogical practices and approaches used to promote his full participation. During the inclusion experience, the role of the Mauá Student Support Program (MSSP) was understood as a fundamental element throughout the entire process, as it facilitated an effective interface among the student, professors, and psychologists. A significant example of this collaboration is demonstrated through the interaction between MSSP initiatives and the General Mechanics course, which utilized specially developed didactic materials to engage the student in the context and practices of the discipline. In this work, the MSSP methodology is detailed, covering mentoring and psycho-pedagogical support practices, as well as the action plan that was implemented in the General Mechanics course based on the professors' experiences. The results highlight the effectiveness of MSSP practices, the successful adaptation of didactic materials, and the constructive interactions between the student and the professionals involved, all contributing to the student's positive perception of the inclusion process. This report recognizes that a systemic approach to integrating psychology with other disciplines promotes inclusion and fosters a collaborative educational environment.

**Keywords:** Student Inclusion; Psycho-pedagogical Practices; Adapted Teaching Materials.

## 1 Introduction

Including students with disabilities in higher education has emerged as an issue of significant importance, both nationally in Brazil and internationally, driven by legislative milestones and historical advances in promoting inclusive educational rights. The National Education Guidelines and Bases Law and the Convention on the Rights of Persons with Disabilities (CRPD), adopted by the United Nations General Assembly in 2006, represent legal milestones reinforcing the commitment to educational inclusion. Inclusion becomes even more critical with the growing demands for a more equitable society and the recognition of diversity as a fundamental pillar of social and economic development (Brasil, 1996; ONU, 2006). Additionally, social movements and public policies have promoted the search for more inclusive education, recognizing the importance of diversity in enriching the academic environment and providing equal opportunities (UNESCO, 2019). Within this context, including visually impaired students in undergraduate courses is challenging due to the physical, technological and social barriers that can limit their full participation (Sales & Torres, 2022).

The inclusion of these students in engineering courses presents both challenges and unique opportunities. On the one hand, issues related to the accessibility of teaching materials, laboratories, and physical spaces can represent significant obstacles to the entire academic development of these students (Silva & Pimentel, 2021). On the other hand, engineering offers opportunities to apply innovative and technological solutions to overcome these challenges and promote more effective inclusion (Zanatta & Silva, 2021). Hodges, Roncesvalles, and Kwan (2019) point out the importance of adapting teaching practices to promote the inclusion of these students in academic engineering environments. Furthermore, studies indicate the need for an interdisciplinary approach involving psychology and teaching professionals to ensure their academic success and social integration (Ciantelli & Leite, 2022; Holanda et al., 2021).

In this context, professional assistance from psychologists emerges as an important resource in supporting the inclusion, permanence, and accessibility of students in undergraduate programs. Collaboration between psychologists and professors enables the identification of individual needs, the development of personalized support strategies, and the monitoring of the inclusion process (Martinez, 2009). Integrating psycho-pedagogical approaches with educational practices can enhance the effectiveness of interventions and promote a more welcoming and inclusive academic environment for all students, not just those who need specific adaptations, facilitating their academic participation and personal and professional development. Applying psychology in the university context involves navigating a complex network of interpersonal and subjective relationships. This demands both theoretically based and ethical interventions to support the development of everyone involved, including teachers, students, and the institution itself.

The Mauá Student Support Program (MSSP) plays a central role in promoting student inclusion at the University Center of the Mauá Institute of Technology (UN-MIT), a private higher education institution (HEI) in southeastern Brazil. By establishing a practical interface between teachers, students and professionals in the psychological field, MSSP enables the implementation of personalized support and monitoring strategies and assumes the role of giving visibility to students' demands and subjectivities in order to design individual and/or collective actions based on these needs (Mello, Caldeira, & da Matta, 2022).

The UN-MIT offers a concrete example of the benefits of this collaborative approach, specifically by including a visually impaired student in the General Mechanics course taught to all Engineering majors. In this case, cooperation between professionals resulted in successful re-adaptation methodologies and teaching materials previously developed at the same HEI, especially for a subject that develops technical drawing skills (Todaro and Lebrão, 2023a, 2023b). Throughout this article, we aim to explore these themes in more detail, presenting concrete evidence and an in-depth analysis of the challenges and opportunities associated with including a visually impaired student in an undergraduate Engineering program. Finally, this article explores and analyzes the importance and challenges of implementing effective inclusion strategies in the context.

## 2 Method

A qualitative methodological approach was adopted to achieve the objectives outlined in this study (Bogdan & Biklen, 2007; Patton, 2015), focusing on participant observation and the analysis of documents and reports pertinent to the context of the inclusion of a visually impaired student in the Engineering program at the University Center of the Mauá Institute of Technology (UN-MIT). Through participant observation, the researchers were able to immerse themselves in the daily practices of the Mauá Student Support Program (MSSP), systematically recording the interactions among the student, teachers and psychologists.

Additionally, documents such as MSSP monitoring reports adapted teaching materials used in the General Mechanics course and records of planning meetings among teachers, students and psychology professionals were analyzed. This approach allowed for an in-depth understanding of the strategies employed to promote inclusion and the student's full participation in the academic environment and provided an evaluation of the results. In this work, the student is Pedro (fictitious name), a 22-year-old regular student in the Engineering program, and classified by Brazilian Ministry of Health (2008) as a visually impaired person, since he has had low vision since his childhood.

## 2.1 Mauá Student Support Program

The Mauá Student Support Program (MSSP) was designed based on best practices and protocols developed in the university environment and the expertise of professionals. MSSP is essential in fostering students' academic success and well-being by offering various services. It is staffed by two psychologists and two teachers from the foundation year of the Engineering program. The staff is responsible for providing emotional support to students, creating a safe and confidential environment to discuss psychological issues, develop coping skills, and facilitate their adaptation, integration, and permanence. It includes counseling on academic, social and personal issues. Furthermore, it fosters close collaboration with other services and professionals at the institution to ensure a comprehensive and integrated approach to student support. By offering multifaceted and personalized support, MSSP plays a crucial role in strengthening the academic community and promoting the success of all students.

The Support, Permanence and Accessibility Center (SPAC), as a complement to MSSP, actively identifies students in need of initiatives for inclusion and equal opportunities initiatives. It conducts academic and socioemotional monitoring and maps their various diagnoses to adapt pedagogical strategies and teaching accessibility. It involves parents, legal guardians, and health professionals setting up a support network when necessary.

## 2.2 Pedagogical actions

General Mechanics course aims to develop skills inherent in the analysis of dynamic systems, and it does so by applying fundamental concepts and models of the kinematics and dynamics of material points and rigid bodies (França & Matsumura, 2011). For this reason, the course proposes studying a series of plane and spatial mechanisms, each with its specific purpose. The academic staff chose to offer students the reproduction of mechanical systems using printed models and to incorporate them, with procedural adaptations, into the tactile module made by Todaro and Lebrão (2023a), due to the objects of analysis proposed by the course are presented to undergraduates using either illustrations or graphic representations.

Before discussing the methodology used, it is important to point out that Todaro and Lebrão (2023a, 2023b) proposed tactile modules as tools for students participating in the Technical Drawing class at the same Higher Education Institution (HEI), which was offered in a competency-based format (Todaro & Lebrão, 2022). These devices were made according to recommendations suggested by Duarte (2004a, 2004b), Almeida, Santos, et al. (2017) and Fucks (2018). Specific details can be found on the works written by Todaro and Lebrão (2023a, 2023b); but, in a general way, the establishment of relationships between pins and cords in the spatial domain of a module, which reproduces technical drawing meshes using calibrated holes, is the foundational principle for using tactile materials. The module was used as a Cartesian reference for analyzing both flat and three-dimensional mechanisms, even though the subject of General Mechanics does not require students to tactilely map standardized contours.

Therefore, the tactile modules accommodated the mechanisms proposed during face-to-face classes, ensuring they were similar to the models presented through conventional illustrations. Thus, the experience offered to the student involved sensory perception of the mechanism and reproduction of the associated movement. This means that the model not only allowed the referred student to tactically perceive the contours of the proposed system but also enabled him to reproduce the typical movements of the mechanisms referenced. Figure 1 illustrates the model used to reproduce the operation of a planar mechanism in one of the classes, aiming to develop mathematical models that can predict the kinematic parameters of a material point moving along a linear guide. In this case, the functions defining the trajectory of the material point and the sliding speed of an arm attached to a horizontal guide were known.

Similarly, Figure 2 depicts a model created to reproduce a three-dimensional mechanism used when investigating mechanisms involving relative movement between components. This model is specifically designed to discuss about kinematic parameters of a mobile component that moves at a constant speed along the guide and couples to an element rotating at a constant angular speed. The mechanisms attached to the tactile module are not fixed; they are designed to allow students to study them in different configurations.

**Illustration of the mechanism studied** **Reproduction of the mechanism in a tactile module**

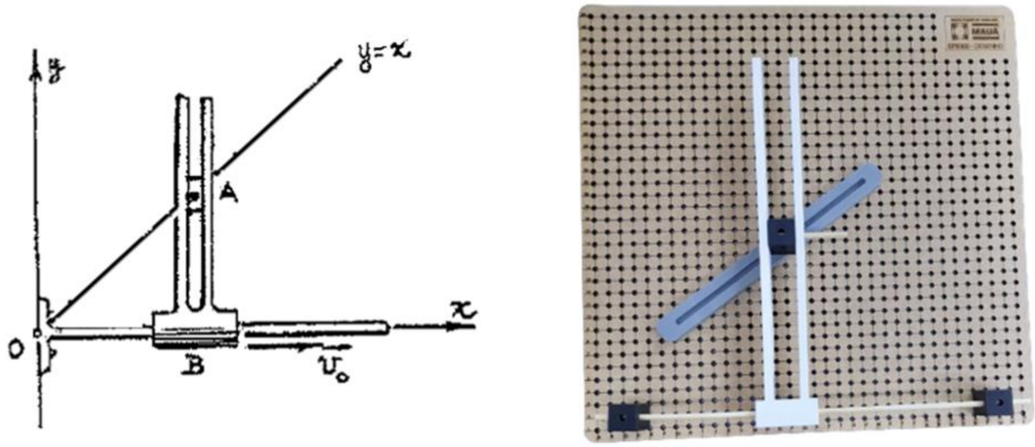


Figure 1. A two-dimensional model capable of reproducing the movement of a material point in a rectilinear trajectory is constructed under the influence of a guide attached to a horizontal reference

**Illustration of the mechanism studied** **Reproduction of the mechanism in a tactile module**

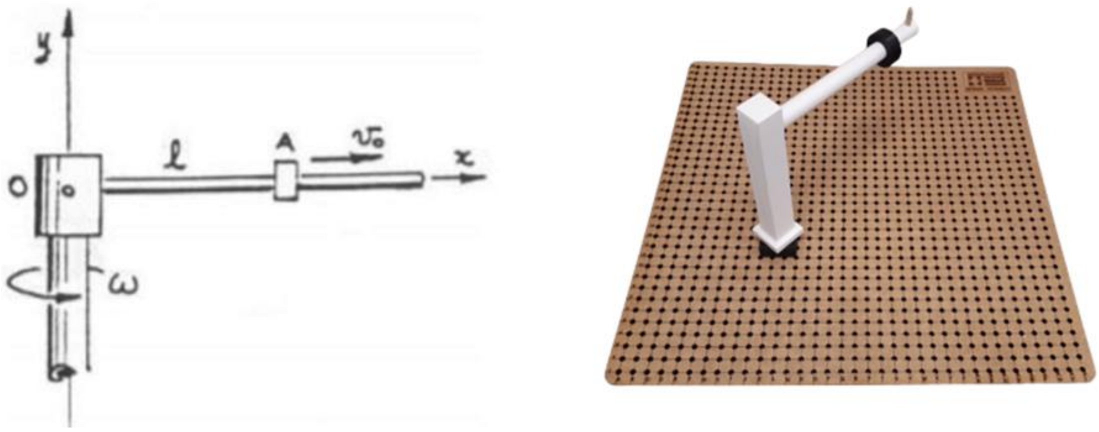


Figure 2. A three-dimensional model capable of reproducing the movement of a body about a guide attached to a rotating structure is constructed

The examples presented are part of a set of experiences designed to bring visually impaired students closer to the practices proposed by the course. Therefore, the timely availability of teaching materials in face-to-face classes was the alternative found for students to develop specific skills in an environment based on their autonomy.

# 3 Results

The presence of a visually impaired student prompted discussions among the Mauá Student Support Program staff, the teachers, and the student himself, instigating a reflection on adapting teaching practices. This context has started to review paradigms and premises related to teaching the exact sciences. Traditionally, these have relied on a single method of transmitting knowledge and abstract physics concepts through visual resources.

The MSSP is committed to monitoring all students who need adaptation and accessibility. Additionally, the teachers also carry out this monitoring, which allows them to engage positively with the student. Students are individuals in development, full of desires and potential. Even in the face of possible limitations such as visual impairment, they need support to stay on their chosen career path and achieve an excellent academic education.

In order to cultivate an environment that is both welcoming and inclusive, we conducted initial interviews to gain insights into the student’s academic history, past experiences in school (both positive and negative), familiarity with technological resources, social skills, level of autonomy and independence, emotional considerations related to their disability, and support from family members and external professionals, among other relevant factors. It is essential to know the student's background in order to understand their limitations and potential.

As such, it is essential to note that since childhood, Pedro has had consistent family support that projects him as a person with only one physical limitation: low vision. Pedro was not literate in Braille and did not use a stick to get around, factors that do not reduce his autonomy. In addition, he has had professionals throughout his life who have stimulated his ability to interpret curves and shapes, giving him positive accuracy in terms of his spatial ability. He has previous training in economics and shows a facility for understanding and performing mathematics.

Considering Pedro's previous experiences, such as suitable stimuli throughout his life and a previous degree, his initiative and proactivity in the face of challenges are visible. He communicates what he needs and tells us what changes need to be made so that he can get it done - the staff's primary concern. In addition, his spatial representation is preserved. This information was fundamental to creating a diagnostic assessment of the student's needs and, mainly, establishing rapport and building a bond of trust between the student and the institution, essential for an environment conducive to a student-centered teaching-learning process.

The next step involved meetings with the professors before classes began, during which the students' abilities and resources were shared, inviting the professors to experiment with different teaching approaches to meet individual learning needs better. The teachers could creatively and qualitatively expand the technical and pedagogical resources available for teaching their subjects based on the content to be taught and the student's physical and cognitive abilities. The literature suggests this is the path to inclusion (Ciantelli & Leite, 2022; Sales & Torres, 2022; Silva & Pimentel, 2021; Zanata & Silva, 2021). Adaptation is not just about modifying existing instruments to provide a "new form of visualization" but about creating resources that enable learning through other sensory capacities, such as touch and hearing.

The leading assistive technologies and digital literacy for visually impaired students in higher education are pointed out in the literature, including the 3D printer, and encourage the search for continuous improvements in adaptation (Tamy et al., 2022). This study used the tactile module to reproduce the piece, an assistive technology with little academic backing. The staff's biggest concern is getting the student to do what is proposed. To address this, they must identify the best way for the student to implement it, considering their abilities and limitations. In the same way, the service provided by MSSP puts the student at the centre and assesses with them what adaptations and needs are required.

Although using visual aids has historically been a common practice and recognized as a quality pedagogical support, the shift to an educational approach centered on the student and their integral skills, which are not limited to visual acuity, raises questions about this practice. It was possible to identify new communication strategies between teacher and student, resulting in a satisfactory teaching and learning process by adopting an approach that starts from the concepts to be taught and considers the student's abstraction and knowledge absorption conditions.

The experience demonstrated a demand for voluntary training of professionals and for careful didactic-pedagogical actions given the expectations of those involved regarding the student's adaptation and success. Throughout the process, it became clear that forming a collective, multidisciplinary initiative aims to enhance the student's practical learning and inclusion in the university environment. In this way, the use of the materials developed by Todaro and Lebrão (2023a, 2023b), adapted for the study of planar and spatial mechanisms, enabled the student to be included in the context of the General Mechanics course, with no discernment compared to students with normal vision.

From a technical point of view, the visually impaired student had ample contact with the suggested systems and was not limited to descriptions but also had the opportunity to simulate the movement inherent in each mechanism he was asked to analyze. Additionally, it is worth noting that the student successfully associated terms from specific mathematical models more efficiently when we made the tactile model available while using the materials. However, it can be inferred that the student has developed his specific skills with the help of the teaching materials; however, he manifests them independently of these devices.

Another point observed was the openness of the subject professor, who was incredibly dedicated to evaluating and building materials in the HEI's laboratories. In addition, the institution provided the student with the exclusive assistance of a monitor to support the inclusion process. Throughout the year, the student often expressed the need for academic monitors only on specific occasions, such as the application of assessment activities and when it was necessary to manipulate multiple objects simultaneously.

Overall, the process conducted between the MSSP professionals, and the teaching staff was positive in emotional terms, demonstrating the effectiveness of a collaborative, student-centered approach to promoting the inclusion and academic development of students with special needs. The belief is that the alignment the MSSP coordinators made with the student, the support monitor, the psychologists, the academic staff, and the institution's administrative staff was the difference in effectively achieving inclusion.

Although the report presented here was a positive and successful experience, it is essential to note that the path is one of trial and error. Experiments that are not successful are often not published and shared, but they must be validated similarly. This shows how actively advancing new technologies for inclusion can gain visibility and enhance the quality of teaching. In addition, there is an expectation from those involved that the student will adapt and succeed. It is necessary to be trained, think and act differently, and look for tools and studies that have already dealt with these adaptations to provide a solution that facilitates the student's learning.

# 4 Conclusion

This article aims to present evidence on the barriers and challenges related to integrating a visually impaired student into an Engineering program, assisted by a team that included psychologists and professors. It is an action carried out in a complementary way.

Therefore, people with special educational needs must overcome the representation based on incapacity, inefficiency and unproductivity. It is the role of the HEI and its staff to find ways of fostering the development of student's skills and abilities. In this case, the MSSP-student-professor relationship stands out as successful in adapting and promoting educational practices.

Ultimately, the primary objective of this process is to empower students with the tools they need to achieve autonomy, quality of life and social inclusion, thus promoting a significant transformation in their educational journey. Future studies and applications must consider these aspects as fundamental foundations for developing inclusive and effective practices in the university environment and society.

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# Navigating Engineering Capstone Strategies

Luciano P. Soares, Luciana C. Lima, Raul I. G. da Silva

Insper Instituto de Ensino e Pesquisa, São Paulo, Brazil

Email: lpsoares@insper.edu.br, lucianacl@insper.edu.br, rauligs@insper.edu.br

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**Abstract**

Capstone is an academic project undertaken by students in their final years of an engineering program, typically a requirement for graduation and often involving external partners. This project offers a valuable opportunity to assess students' readiness for the job market by engaging them in complex projects that address real-world challenges. However, ensuring the success of such initiatives requires comprehensive support and ongoing communication among all stakeholders. This paper presents a series of pedagogical strategies for organizing a Capstone program and preparing students to handle real-life project challenges. The main goal is to ensure students understand project objectives, involve company mentors in clarifying challenges, and enable comprehensive monitoring by academic advisors. Students and advisors need a clear understanding of the project's time commitment and desired outcomes. Several strategies are developed to enhance the Capstone experience for all stakeholders involved. This Capstone program engaged 551 students and 73 companies, yielding 151 successful projects despite occasional student setbacks. Ongoing positive feedback from companies underscores the program's enduring value each semester.

**Keywords**: Capstone Projects; Expectation Management; Project Kick-off Readiness.

## 1 Introduction

The job market has changed in recent decades, and education systems should adapt to ensure the skills demanded by society are met. In this regard, engineering programs have been adjusting their curriculum, incorporating real-life projects into the classroom. These projects encompass various challenges, including communication, organization, and, of course, technical skills. This shift has become a requirement regulated by government and accreditation organizations.

In Brazil, the Ministry of Education defines a set of competencies aligned with a professional profile supported by a holistic and humanistic approach. These competencies include analytical skills, research and development of innovative solutions, entrepreneurship, teamwork, communication, among other skills. They are outlined in the National Curriculum Guidelines for Undergraduate Engineering Courses (BRASIL, 2019). These guidelines also explicitly state that engineering programs must include a final project to confirm students have developed all necessary competencies. This guideline presents a mandatory curricular component that can be interpreted as a Capstone program, with a focus aimed at solving concrete problems, whether in the productive sector or in society at large.

In the context of ABET (Accreditation Board for Engineering and Technology), a nonprofit organization that accredits college and university programs worldwide, emphasis is placed on the need for engineering programs to demonstrate that their graduates have achieved various educational outcomes. While the term "Capstone" is not explicitly mentioned, ABET requires engineering programs to provide "a culminating major design experience" (ABET, 2021), which can be also be interpreted as a Capstone project, expecting projects designed to fulfil this requirement by offering students opportunities to integrate and apply their knowledge and skills to real-world engineering problems.

This document presents the strategies implemented in the Capstone program at Insper (Insper, 2022), demonstrating achieved results. The Capstone Project spans one semester, during which students should develop and apply technical and interpersonal skills in a real and highly complex situation. In this sense, we argue that the engineering courses should promote technical combined with interpersonal competencies applied in a real and complex challenge to intensify the students' formation. This project is supervised by a multidisciplinary group of advisors and mentors. This structure of the Capstone requires comprehensive support from students and ongoing communication among various stakeholders, aligning with the concept of competence, which entails transforming knowledge and skills into practical results (Spencer & Spencer, 1993).

The following sections begin with a brief review of changes in engineering education impacted by Capstone programs. Then, the capstone project in Insper is analysed in more details and the results are discussed. Finally, the conclusions are presented.

## 2 Professional Engineering Education in Capstone

Baena et al. (2017) defends that engineering education has a strong link with the global economy and social development, therefore its role implies impacts and is simultaneously influenced by innovation technology. In this context, it is estimated that 43% of human tasks will be performed by machines in 2027 (World Economic Forum, 2023) and the rest will be based on relational tasks (Mercer, 2023). In addition, the five most important skills for business in 2027, described by the Future of Jobs Report (World Economic Forum, 2023), are creative thinking, analytical thinking, IA and big data, and leadership and social influence.

These points show that the engineering job is changing, but at the same time is yet very important to the society. And preparing engineering for the society is challenging, especially since the number of students applying for engineering is reducing (The Economic Times, 2023), and in addition, the Anísio Teixeira National Institute of Educational Studies and Research (INEP) has shown that the dropout index in private undergraduate courses is around 20% per year in Brazil (Christo, de Resende & Kuhn, 2018).

Considering the job market challenges and the dropout index context a set of strategies have been adopted by universities to make the engineering courses more attractive and updated. One of the strategies is to adopt an active learning methodology, e.g. Project Based Learning, as the main approach during the classes to facilitate the development of students' protagonism and leadership and social influence skills (Vieira & Lima, 2019).

Capstone Project could be interpreted as a type of Project Based Learning (PBL) methodology because students, working in groups, need to demonstrate competences of investigation and design creatively solutions (Shurin, Davidovitch & Shoval, 2021). Hauhart & Grahe (2015) show that the Capstone programs are becoming more popular, they estimate that in 1970s only 3% only all academic institutions adopted this practice, while authors report an average of 66%-75% at the time of the publication. Part of this growth probably came from the accreditation process, e.g., ABET (The Accreditation Board for Engineering and Technology), and pressure from other organizations dedicated to improving engineering education, e.g., ASEE (American Society for Engineering Education).

One study conducted by Howe and Goldberg (2019) in 2015 and involved the last 25 years of engineering capstone design education and includes 522 respondents from 256 institutions shows that (Table 1).

Table 1: Interpretation of Survey on Capstone Programs in Mechanical Engineering.

| | |
|---|---|
| Number of different disciplines | At least two different disciplines – 52%<br>At least five different disciplines – 11% |
| Duration | More than 50% last for 2 consecutive semesters |
| Frequency meets with a faculty coach | Weekly |
| Topics covered | Analysis tools; CAD design; Concept Generation; Concept Selection; Creativity and Problem Solving; Decision Making; Engineering Ethics; Functional Specifications; Intellectual Property; Leadership; Optimization; Oral Communication; Project Management, Prototyping and Testing, Sketching, Standards and Regulation, Sustainability, Teamwork, Written Communication |
| Evaluators (high input on course grade) | Course instructor – 83%<br>Project advisor/coacher - 36%<br>Industry liaisons – 8%<br>Peers – 3% |
| Evaluations of deliverable<br>(Interviewees can select multiple options) | Final written report – 77%<br>Final oral presentation – 63%<br>Final product – 62% |
| Industry/government<br>Faculty research | 87%<br>64% |
| Team size | More than 80% have between 3-5 students |
| Method for assigning students to teams<br>(Interviewees can select multiple options) | Student choice - 72%<br>Instructure choice – 48%<br>Student skills for project – 44% |

Source: Adapted by authors from Howe and Goldberg (2019)

Two contents were not considered in the study above. The first is the student's perception of the Capstone success, Rashwan et al. (2020) defends that different perspectives regarding to this are discussed in the literature, e.g. sponsor, faculty member, however the student view if the project was a success were receiving little attention. The second is the assessment rubrics and the authors argue that despite its being a common practice and most of the time following the ABET requirement, it does not emphasize enough soft skills such as teamwork effectiveness and leadership skills.

In a systematic review to investigate current efforts and practices more visible and accessible in capstone design experiences, Zheng et al. (2021) analysed studies published between 2006 and 2020 that satisfy the multidisciplinary needs from ABET. The final 36 results show that the most common focus of papers on capstone projects was related to sharing experiences or structure of one specific capstone project.

Zheng et al. (2021) suggest that the effectiveness of capstone projects as a major gap in the investigation of capstone fields once it's often not validated because of the lack of project evaluation data or results, especially in multidisciplinary capstone.

## 3 Capstone Project at Insper

The Capstone projects at Insper are in line with active learning strategies, where students learn by doing, with support from an experienced advisor. This approach emphasizes hands-on experience and practical application of knowledge, allowing students to gain valuable insights and skills that are directly applicable to real-world challenges. Through active participation in their projects, students not only deepen their understanding of engineering competences but also develop critical thinking, problem-solving, and teamwork abilities essential for success in their future careers.

**The beginning**

Since its first edition, the capstone project at Insper has adhered to several core principles. These include instilling a sense of professional responsibility in engineering students, working within constraints such as time, budget, and personal interests, and always involving a real external client to provide authentic feedback for the project challenges (Howe & Goldberg, 2019).

Insper offers three engineering programs (computer, mechatronics, and mechanical) that are structured as five-year courses organized into semesters, with a Capstone program in the eighth semester. The first edition of the Capstone program at Insper took place in the second semester of 2018. Following the common practice observed in universities across the USA, the program had a duration of one year, organized into two consecutive semesters. Students were expected to dedicate a total of 300 hours, or 150 hours per semester in the Capstone project, allowing time for taking three elective courses in parallel with the Capstone project.

A series of weekly two-hour classes addressed pertinent topics aimed at preparing students for the challenges they might encounter during their projects, the most common topic was oriented to project management, exploring different strategies. Typically, there are approximately 12 classes, with most of the classes oriented to some activities with all the groups, and the remaining sessions dedicated to group reviews, such as team dynamics, report quality assessment, or other forms of mentoring. Additionally, students were required to visit companies once a week, typically spending several hours working in the company offices.

Students have three main assessment points that are always based on the Capstone competences: one individual assessment and another for the entire group, both evaluated by the project advisor. The third assessment is conducted by an evaluation committee composed of at least three professors. These evaluations occur in the middle of the semester and at the end of the semester.

**Adjustments**

The initial adjustment made to the Capstone program was transitioning from a two-semester format to a single semester. This change was implemented mainly because students often participate in internship programs during their final undergraduate year, which could lead to conflicts with the Capstone project. This change consolidates a 300-hour commitment into a semester. The dedication was later expanded and is currently 360-hour.

Another important adjustment relates to the Capstone competencies. Originally, the competencies were: technical, organization, communication, teamwork, and design & entrepreneurship. Note that 'design & entrepreneurship' was considered a single competency group. However, from the advisors' perspective, evaluating 'design & entrepreneurship' was complicated since it mixed topics that should not be combined. Therefore, this competency group was split into design and entrepreneurial attitude.

The topics covered in classes also changed. In the inaugural edition, there were four days dedicated to project management classes and two days for organizational culture classes. However, by 2024, the curriculum evolved, with only one class focusing on project management, and the content of organizational culture was restructured into sessions oriented towards Communication, Value Proposition, and Career development. Additionally, other essential classes are regularly taught each semester, including Scientific Methodology, Ethical Responsibility, Intellectual Property, Decision Making, Technical Standards, and Effective Presentations. Classes were also moved from Thursday’s afternoon to Friday’s morning to avoid collision with other possible elective courses that students may be interested to take.

Several other adjustments were implemented, including advisors creating orientation plans for the semesters, reorganizing and reviewing learning goals and rubrics, determining the necessary information for reports, and creating videos and posters. However, these topics are beyond the scope of this document.

For two consecutive semesters, all classes were condensed into a single week prior to the start of the projects. This attempt was made to cover all important topics before the projects began. However, this approach did not work well; students appeared visibly tired, and their concentration levels were too low. Consequently, classes reverted to the weekly model.

# 4 Educational Strategies

Several educational strategies were developed and implemented with Capstone students to enhance learning, organization, team dynamics, communication, among other benefits. Below is a list of some pertinent strategies employed, which could serve as valuable models for other Capstone programs.

## 4.1 Golden Rules

In the first class of the Insper Capstone program, students are tasked with articulating their expectations for the project in a comprehensive document. This document serves as an official reference throughout the semester, primarily focusing on fostering alignment within the team and clarifying individual commitments. Given the diverse dedication levels and interests among students involved in the project, this alignment is crucial for ensuring cohesion and progress. By formalizing and documenting these expectations, teams can cultivate a better working environment, minimizing potential frustrations among members and facilitating the planning of subsequent project milestones. This type of agreement usually encourages students to take more responsibility for their project, as they have officially written down their commitment, typically indicating a high level of dedication.

In this activity, students must answer these 3 questions:

- What are we absolutely not going to do during the Capstone?
- What will we always remember to do when facing a challenge in the Capstone?
- What is our purpose - as a team - in carrying out the Capstone?

## 4.2 Communication Activities

The Insper Capstone is a significant project that students dedicate themselves to for an extended period, typically around five months or one academic semester. Throughout this timeframe, students engage in weekly hour-long meetings with a mentor from the partnering company. Additionally, they receive guidance from an Insper faculty member, meeting with them for about two hours each week. An essential aspect of the project is learning to communicate effectively in different contexts, such as academic and professional settings. One of the Capstone classes is aimed at enabling students to acquire skills to navigate these varied communication styles. In this class, examples of communication are presented to the students, who must identify styles and respond with strategies for interacting with others.

## 4.3 Regular Week Dedication Planning

Advisors, partners, and the institution require a clear understanding of the students' regular time commitments. Therefore, a detailed allocation plan is requested and regularly updated to streamline meeting schedules and identify any lower-than-expected dedication. This is another crucial activity conducted during Capstone classes, where students' hours of dedication are discussed and monitored. The primary goal is to complete the timetable (Table 2) with the hours each team member will dedicate to the project, considering that students may have different elective courses with varying schedules. However, a minimum of 22 hours per week is expected for the Capstone project. Subsequently, students are asked to identify the hours they will work together in the team, with a minimum requirement of 8 hours collectively every week. While this requirement may be complex due to students' individual commitments throughout the week, it serves to gauge the alignment of dedication. A significant deviation in dedication among team members or limited time slots for the entire team to work together can indicate potential teamwork issues. With this tool, problems can be identified and preventively addressed.

Table 2. Time Dedication Planning per Week.

| | Monday | | | | Tuesday | | | | Wednesday | | | | Thursday | | | | Friday | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | E1 | E2 | E3 | E4 | E1 | E2 | E3 | E4 | E1 | E2 | E3 | E4 | E1 | E2 | E3 | E4 | E1 | E2 | E3 | E4 |
| 7:30 - 9:30 hs | | | | | | | | | | | | | | | | | | | | |
| 9:45 - 11:45 hs | | | | | | | | | | | | | | | | | Capstone Class | | | |
| 11:45 - 13:30 hs | | | | | | | | | | | | | | | | | | | | |
| 13:30 - 15:30 hs | | | | | | | | | | | | | | | | | | | | |
| 15:45 - 17:45 hs | | | | | | | | | | | | | | | | | | | | |
| 18:00 - 20:00 hs ( optional) | | | | | | | | | | | | | | | | | | | | |
| 20:00 - 22:00 hs ( optional) | | | | | | | | | | | | | | | | | | | | |

## 4.4 Engineering Standards

Real engineering projects often encounter stringent regulations from various entities, including governmental bodies. It is essential for students to be well-prepared to navigate through these standards, ensuring both quality and maintainability in their projects. As part of the Capstone program, one of the proposed activities is for students to carefully evaluate the potential standards that may impact their projects. This initiative aligns directly with the core objectives of the Insper engineering program, emphasizing the importance of students comprehending the contextual environment within which their projects operate.

Given that the projects are conducted in Brazil, the primary authority defining standards within the country is the ABNT (Brazilian National Standards Organization). However, in today's globalized world, the engineering landscape transcends national boundaries. Hence, students must also be equipped to navigate international standards such as ISO (International Organization for Standardization), CEN (European Committee for Standardization), IEEE (Institute of Electrical and Electronics Engineers), and ASTM (American Society for Testing and Materials).

## 4.5 Fortnightly Reports

While students regularly meet with advisors and mentors, there is a system in place to monitor their progress and activities throughout the capstone process. Every two weeks, students are required to document how they have allocated their time to the project, detailing the tasks undertaken and the number of hours spent on each task. Although these reports are not directly evaluated, they serve as a tool for students and advisors to assess whether the progress is adequate. This practice proves very convenient for advisors during the final evaluation phase, enabling them to closely monitor each student's progress and assess the adequacy of their work. One of the identified problems was that students were reporting group work in the report, when the intention was to identify individual contributions, even if they collaborated most of the time in tasks. Therefore, there is an emphasis on the requirement to report personal contributions.

The guidance provided to students for completing the report is as follows: “Briefly describe YOUR contributions to the project, what YOUR learnings were, what skills YOU developed during this last period. If you wish, you can also make a brief reflection on how you could contribute more efficiently to the project in the coming weeks. Please indicate the approximate number of hours you have dedicated to the project since the last fortnightly report.”

# 5 Results

The primary source of information within the Capstone program is derived from student feedback. Students were surveyed regarding the depth of their learning experience throughout the Capstone activities. The graph below (Figure 1) illustrates data from the four most recent editions of the Capstone program.

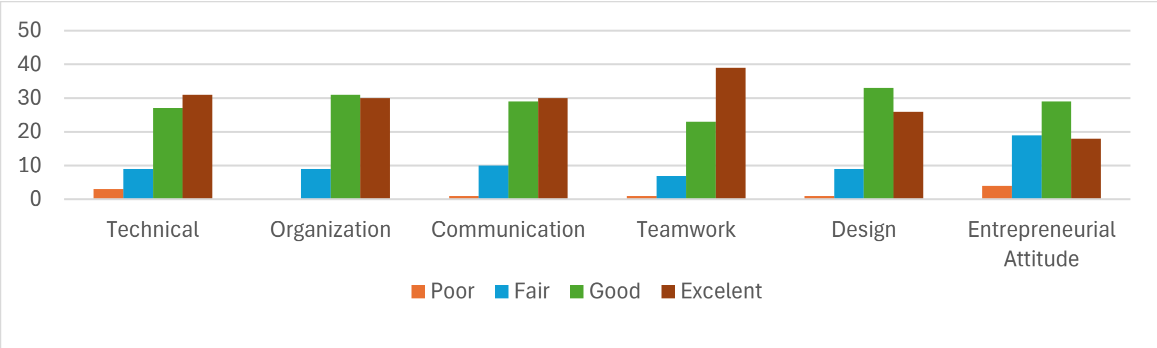


Figure 1. How students identify their learning levels for each main competence

It is evident that teamwork emerges as the most significant perceived competency developed by students throughout the Capstone program, since students are grouped with other students and must face a longer project where many issues may arise. The main orientation passed for advisors on how to prepare students is that groups must be self-organized and self-managed, and advisors should check if the harmony of the group is efficient. As necessary, advisors have individual meetings to identify group problems. Since the implemented Capstone projects mix students from different major, many teams have students that are not used to work together, creating an additional challenge that is important for learning teamwork.

The following graph (Figure 2) presents how do groups evaluate the working dynamics of their group. This graph also shows results from the last four editions of the Capstone program.

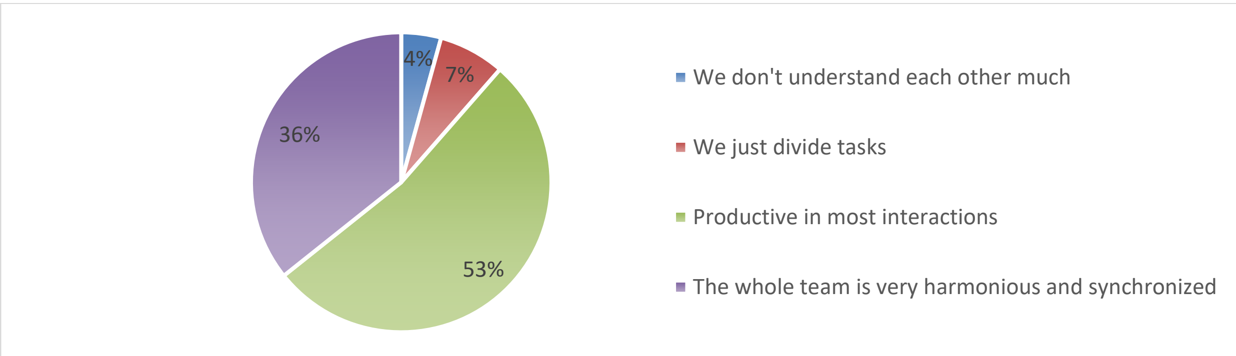


Figure 2. How students evaluate their group dynamics

The graph clearly illustrates that while some groups encounter teamwork challenges, the majority exhibit harmony. However, there is a high expectation for students to assess their competencies in entrepreneurial attitude. Many students struggle with negotiating with stakeholders and encounter difficulties in risk planning.

There is a big challenge in the perception of importance of the regular classes taught, while the discussions in the faculty meeting leading to a consensus that the classes are important and relevant for student formation, but even in the last years students have regular feedback, around 50% of the students do not consider the classes important for their formation, while the other 50% think it is important. The results are very stable, even changing topics, professors, and weekday for the classes (Figure 3).

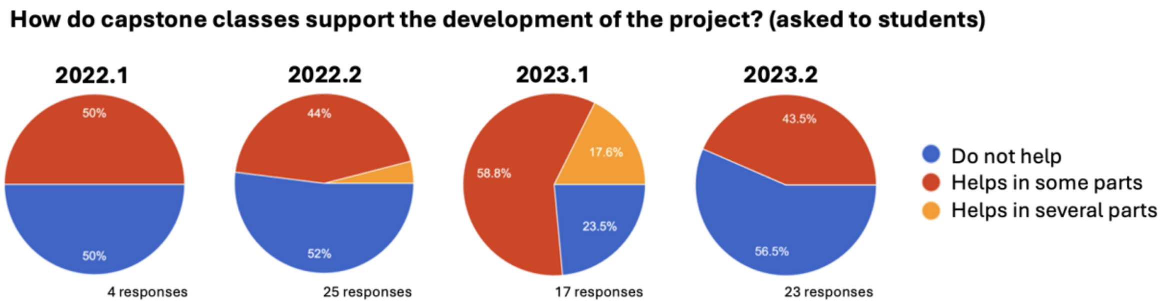


Figure 3. Perception of importance of capstone classes by students

## 6 Conclusion

This document presents the strategies implemented in the Capstone program at Insper (Insper, 2022). With 12 editions already completed, ongoing adjustments continue to refine the program. Strategies such as the Golden Rule, where students create a document aligning their expected dedication to the project, have a direct impact on group dynamics since team members are not self-selected, and this commitment among members must be clear and as official as possible. Regular Week Dedication Planning, which enables students to plan their meetings and team activities efficiently, is another simple tool that provides a clear understanding of how each team member will dedicate time to the project. Additionally, Fortnightly Reports ensure continuous monitoring of student progress, helping to identify problems early, well before the intermediate reports, thereby improving the chances of success for both the project and the learning goals.

There are several other strategies commonly used in engineering capstone programs that are also employed in the presented program. These include the following deliverables: a planning report, individual and group reports, slides from the evaluation board, a demonstration video, a banner for the closing ceremony, and a reviewed report.

These strategies have been thoroughly tested, and upon recognition of their value by faculty, have been established as official and integral components of the Capstone program. Furthermore, the findings of Figure 1 are consistent with the literature gap Rashwan et al. (2020) discussed, as long as they cover the undergraduate perspective on the capstone. Since its not considered in the grade, it's used to improve the content and schedule.

This capstone program already had 12 editions that involved 551 students and 73 different companies, resulting in 151 projects, all of which were successfully completed, contradicting the results shown in Figure 3. The content of the capstone class was changed during the program, and the number of respondents does not reach 50% of the total number of the capstone class. Meanwhile, positive feedback from the companies underscores the program's value, which continues to be applied semester after semester. The average Net

Promoter Score (NPS) from partner companies that have concluded projects thus far is 9.31, indicating a favourable perception of the students' and projects' quality. These results are also in line with Zheng et al.'s (2021) assertion for the effectiveness analysis of the capstone projects.

Artificial Intelligence tools were used to review the text of this paper, as English is not the authors' native language. However, the tool was not used to create new content.

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# Experience in the Implementation of a Permanence Strategy in Virtual Training in Technology

Liz Karen Herrera-Quintero[1], Fredy Andres Olarte-Dussan[2]

[1] Department of Mechanical and Mechatronic Engineering, Faculty of Engineering, Universidad Nacional de Colombia.
[2] Department of Electrical and Electronic Engineering, Faculty of Engineering, Universidad Nacional de Colombia.

Email: lkherreraq@unal.edu.co, faolarted@unal.edu.co

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**Abstract**

In 2023, the National University of Colombia, in a groundbreaking collaboration with the District Agency for Higher Education, Science, and Technology, pioneered a virtual training program specifically tailored for adult high school graduates. This innovative program was structured around four distinct technical lines: UI/UX interface design, mobile application development, digital animation, and video game development. It offered both basic and intermediate levels of training, with each level encompassing approximately 280 hours of comprehensive learning. Different actions were implemented to mitigate attrition during training, resulting in a significant increase in permanence compared to typical levels of virtual learning. The strategy included a data analysis system to estimate each individual's dropout risk, weekly calls to possible dropouts referred by tutors, follow-up of individuals requesting support in psychological and academic aspects, consultations referring to the National University, and the health network. Additionally, direct communication was established with potential dropouts through withdrawal tickets and psychosocial accompaniment to support students in increasing motivation and reducing anxiety, depression, and stress. On the other hand, peer learning was included, consisting of a mentorship program that invited students; a sponsor plan was implemented that asked those who voluntarily wanted to share their knowledge with those who needed support in the most challenging subjects. Lastly, motivational messages were emailed to encourage students to complete the course. The program had three groups throughout the year with similar population characteristics. The attrition rates were 9,7% for group 1, 5% for group 2, and 7% for group 3. Typically, this type of training has a dropout rate of around 30%, so the implemented strategy significantly positively affected the students' permanence in the program

**Keywords**: virtual learning, data analysis, peer learning, digital skills.

## 1 Introduction

Virtual education, also known as online education or distance education, refers to the teaching modality that uses information and communication technologies (ICT) to facilitate learning outside the traditional classroom environment (Rawashdeh, AZ. *et al.*, 2021). This modality has experienced significant growth in recent decades, transforming how people access education (Haleem A. *et al.*, 2022). Virtual education has its roots in distance education, which dates back to the 19th century with the creation of correspondence programs. With the advancement of communication technologies, such as radio and television, distance education evolved and adopted new forms of teaching. Virtual education has become an effective and accessible educational modality for millions worldwide (Betts K. *et al.*, 2020).

Virtual education is characterized by using digital platforms and multimedia resources to teach classes, carry out educational activities, and evaluate student learning. Through these tools, students can access educational content, interact with their peers and teachers, and carry out learning activities flexibly adapted to their needs (García Aretio, L., 2001). Some of the advantages described of this type of education are access to education, which allows students to access it from anywhere, as long as they have access to the internet; removing geographical barriers, and facilitating access to education for people living in remote areas or with mobility difficulties (Becerra, G. E., 2017). Another advantage is the flexibility of schedules, which makes it easier for students to combine study with other responsibilities, such as work or family. Virtual education has allowed a more excellent choice and variety of programs and courses previously unavailable in specific geographies (Sanabria Cárdenas, I., 2020). This will enable students to choose programs that best suit their interests and educational needs. In addition, there is a reduction in travel and accommodation expenses for students and academic institutions.

Despite its advantages, virtual education has some essential disadvantages; one of the main criticisms of virtual education is the lack of physical interaction between students and teachers. The absence of face-to-face contact can make it difficult to create social bonds and develop interpersonal communication skills. Likewise, virtual education requires a high degree of motivation and discipline on the part of students, as they do not have the direct supervision of a teacher (Aakash, A., 2022). Some students may struggle and need a set class schedule to stay motivated and organised.

For all of the above, virtual education currently faces several challenges, among which the following stand out: first, to guarantee the quality of distance education. Virtual programs and courses must meet the same quality standards as face-to-face programs, ensuring students acquire the knowledge and skills necessary for their training. Second, teachers' adaptation to new technologies and teaching methodologies. Therefore, teachers must receive adequate training and support to deliver classes effectively in virtual environments. Third, regardless of socioeconomic or geographical status, equitable access to virtual education is another major challenge. This involves ensuring everyone has access to the internet and the technological resources necessary to participate in virtual education (Meza Villares, E. & Soledispa Toala, F., 2023). Fourth, developing safe and efficient educational platforms to ensure virtual education's quality and security comply with data protection and privacy standards (Ruiz Salvador, L. & Álvarez Llerena, C., 2021). Finally, another significant challenge is to develop effective methods for assessing and certifying learning in virtual environments. Finding ways to evaluate student learning somewhat and objectively is critical to ensuring the validity and reliability of results (Azam, R. & Yousef, N., 2010). These challenges are related to the academic success of students and the dropout rate, which is usually higher in this modality than face-to-face training.

Several types of variables affect the dropout rate. Studies on the influence of socioeconomic variables on dropout can be grouped into two large groups: those in which no variable was related to dropout and those in which one or more related variables were found. Within the first group, the study carried out by Orellana *et al*., 2020: a systematic review of the literature on student dropout in virtual higher education programs from 2004 to 2019, in which 52 variables related to dropout were found. However, none of them correspond to socioeconomic aspects. Within the second group, studies by (Barbosa-Camargo *et al*., 2021 Guzmán Rincón *et al*., 2021) have highlighted the role of the schooling of both parents or the mother since having parents with higher levels of education is negatively correlated with dropout. On the other hand, Palacio Sprocket *et al*., 2020 indicate that students from lower-income families are at a disadvantage when entering higher education, given the social and cultural capital.

On the other hand, Soons *et al*. (2009 cited in Guzmán Rincón *et al*., 2021) indicate that the student's perception of well-being mediates the relationship between income and dropout, the higher the income, the greater the perception of well-being and the decrease in the possibility of dropping out. Likewise, funding programs have been found to benefit retention in higher education students (Barbosa-Camargo *et al*., 2021). Finally, regarding the trend in Latin America and the Caribbean, Munizaga Mellado *et al*. (2018) report that in the studies carried out in these areas from 1990 to 2016, the most frequently found variables include financing, income, and, again, educational level of parents (21%).

Gender has been a variable present in different studies on attrition. However, the results have been contradictory. Barbosa-Camargo *et al*. (2021) found that being a woman had a negative correlation with dropout; likewise, Orellana *et al*. (2020) in their systematic review of causes of dropout in virtual environments. However, in other studies, such as that of Olarte Moyano (2020) carried out in a technical institution in Colombia, gender did not show a significant relationship with dropout. On the other hand, age is an individual variable that affects dropout. In the systematic review carried out by Orellana *et al*. (2020), it was found that the older the age, the greater the probability of dropout, especially between the ages of 29 and 35; this finding is supported by other studies reported by Guzmán Rincón *et al*. (2021), although they report that this variable is related to others, especially with work and family obligations, since they compete in time availability with academic work.

Academic performance is related to dropout in two ways: the first refers to accumulated academic capital, and the second to program performance. Students with lower academic capital have a higher risk of dropping out, given the academic demands of higher education (Guzmán Rincón *et al*., 2021); this finding has been replicated in studies conducted in Colombia (Barbosa-Camargo *et al*., 2021) and Chile (Guzmán Rincón *et al*., 2021). Especially in virtual environments, other relevant variables are evidenced, such as time management techniques, educational skills, preparation for self-directed learning, self-efficacy, procrastination, and academic experience (Orellana *et al*., 2020) On the other hand, performance within the program is also related to dropout, the better the performance, the lower the probability of dropping out in both face-to-face and virtual environments (Guzmán Rincón *et al*., 2021; Orellana *et al*., 2020).

Program quality is related to dropout through variables such as (1) teacher-student interaction; the more significant the interaction, the greater the probability of remaining in a virtual program until completion (Stanford-Bowers, 2008, cited by Orellana *et al*., 2020; Guzmán Rincón *et al*., 2021), (2) student-to-student interaction, program design can increase student-to-student interaction and thereby increase student engagement and academic performance; and finally (3) the number of students per teacher (Guzmán Rincón *et al*., 2021). On the other hand, the institution's support variable is also related to dropout; the lower the accompaniment of students through the well-being division, the higher the dropout rate, especially in private institutions (Guzmán Rincón *et al*., 2021).

During 2023, the Faculty of Engineering of the National University of Colombia trained more than 5000 students in Bogota over 18 years of age, allowing them to strengthen IT competencies and 4.0 skills, contributing to the reduction of the digital divide. To execute the Todos a la U program, the University implemented pedagogical processes and methodologies of challenge-based learning in a hybrid training modality to seek alternatives for learning and interaction between students, mentors, and tutors through virtuality assisted by technological means and face-to-face. The following diplomas were taught: Mobile Application Development, Video Game Development, Digital Animation Design, and UX/UI User Interface Design. Each of the diplomas taught was carried out at two levels, basic and intermediate: Basic level: understood as the initial level of each training programme, Intermediate level: understood as the complementary level of each IT industry skills training program.

This paper presents the experience of implementing a dropout reduction strategy in a virtual IT training program developed by the National University of Colombia and the Atenea (Spanish initials for *Agencia Distrital para la Educación Superior, la Ciencia y la Tecnología*).

## 2 Permanence Strategy in Virtual Training

Atenea's student retention strategy focuses on providing vital support that allows students to achieve their academic goals and actively participate in the courses they enrol it. This strategy is committed to offering resources and services specifically designed to address students' individual needs, thereby fostering their academic success and commitment to their education.

In three cohorts, different actions were implemented to mitigate dropout, which had a significant impact and were established as follows: Psychosocial Accompaniment, in which greater motivation and reduction of anxiety, depression, and stress were achieved, which were the leading causes of registration on the button. He was also able to provide an immediate response to a case of suicidal ideation.

The second action consisted of supporting students with low academic performance through a program called "sponsor plan," where students generated a greater understanding of the subjects; the third strategy was based on internal monitoring tools to support student retention. Therefore, it was essential to make weekly calls to possible dropouts referred by tutors and/ or trainers and for absences, in which the primary needs of the students were identified. Subsequently, the respective support was suggested.

Likewise, possible dropouts referred through withdrawal tickets and follow-up to people with special conditions were retained, where any doubts or concerns regarding the course were resolved. Finally, in the fourth action, students were encouraged to complete the program with Motivational Messages and levelling successfully.

## 2.1 Information Sources

In order to establish the appropriate strategies for the beneficiaries, a characterization survey was carried out, asking about socioeconomic level, level of education, belonging to an ethnic group, and whether or not they had any particular condition (visual, physical, mental, language, developmental, etc.). This information generated an exhaustive accompaniment for people who mention some type of difficulty, whether technical, personal, or family. Similarly, greater motivation and retention were established with calls, forms, assistance, and information from tutors, trainers, and the support and help desk team.

The implementation of the Virtual Campus brings a wave of excitement. The online learning platform is not just a technological advancement, but a gateway to a comprehensive, high-quality virtual environment for our participants.

The Virtual Campus is fully operational and accessible to users, becoming the central axis of the training experience. Through this platform, students will be able to access interactive educational content, participate in discussion forums, interact with instructors and peers, and take full advantage of the learning opportunities offered by the program.

Alongside the Virtual Campus, we've made significant strides in improving the unaltodosalau.com Help Desk. The interfaces have been redesigned with user-friendliness in mind, making it a breeze to create and track tickets. We've also integrated a dedicated space for instructional videos, addressing user feedback and providing visual guides for key processes.

The launch of the Virtual Campus and the improvements to the Help Desk reflect Todos a la U's commitment to providing a quality learning experience and exceptional technical support to its participants. These initiatives strengthen the virtual educational environment, promote equitable access to training opportunities, and provide the necessary tools for students' academic success.

## 2.2 Deployed Actions

During the training process, different strategies were implemented to mitigate dropout, which had a significant impact. Some of them were:

### 2.2.1 Sponsor Plan

This plan was open to the voluntary participation of those students who demonstrated a greater understanding of the topics so that through study spaces on the platform, they could share their knowledge and learning with students who reported low academic performance or meager attendance and/or participation in the program. This way, a link of accompaniment between students was generated, and peer support was promoted to help students understand and comprehend academic activities and progress the training process.

### 2.2.2 Psychosocial support

A space for care and support was set up on the training platform with the support of the psychosocial support team. Virtual sessions were held with students who requested it. In these meetings, students were motivated and sought to support the reduction of anxiety, depression, and stress (the main causes of student registration). On the other hand, in order to offer students input to reflect on their progress in the training program and generate motivation to continue in the process, the psychosocial support team made contact by telephone and/or email with participants at risk of dropping out and who reported a shallow level of progress or engagement with the program.

### 2.2.3 Accompaniment to students identified as at higher risk of dropping out

Dropout risk criteria and tools were established to identify and accompany students in this condition. Among the criteria were students with special conditions, with the highest number of fouls that they referred to as some difficulty, who requested tutoring, and who had meager participation during the training progress. Among the detection strategies was a data analytics tool and the support of the team of trainers/tutors. Tutorials were given, communications were advanced, and tickets were created to support them.

### 2.2.4 Other strategies

Other strategies implemented were related to the retention of withdrawal requests, the accompaniment of people who referred some difficulty through a technical help desk, the accompaniment in the uploading of documents at the beginning of the call, and the follow-up of particular cases (suicidal ideation and learning difficulties).

# 3 Results

## 3.1 Cohort 1

A total of 4069 students were enrolled in cohort 1, distributed in eight diploma courses, each with an intensity of 280 hours. 52% (n=2107) obtained a certificate of approval, 19% (n=769) obtained a certificate of attendance, 20% (n=797) failed the diploma course, and 9.7% (n=396) dropped out of the diploma course. The basic level had a dropout rate of 9.4% (n=380), while the intermediate level reported 5.3% (n=16), which could indicate that preliminary knowledge of the subject generates a more excellent permanence in training. Regarding age, the population with the highest dropout rate was in the 18 to 20 age range, with 13.3% (n=110). The number of children of the participants generated a slight difference in the academic result, with the lowest dropout rate among those who had a child at the time of training, with 8.6% (n=54). On the other hand, the stratum had a counterintuitive behaviour; the lowest dropout rate was in stratum one (1) and the highest in stratum four (4).

### 3.2 Cohort 2

The behaviour of cohort 2 was more optimistic; out of a total of 1617 students enrolled in four basic level diploma courses each, with an intensity of 280 hours each, 76% (n=1234) obtained a certificate of approval, 4% (n=62) obtained a certificate of attendance, 15% (n=240) failed the diploma course and 5% (n=81) dropped out of the diploma course. The topic with the highest attrition was UX/UI interface design, with 8.6% (n=28), while mobile app development had 2.9% (n=16). No significant differences were found in age or number of children for this group.

### 3.3 Cohort 3

The last cohort consisted of 500 students who completed the basic level of Cohort 1 and continued their studies at an intermediate level. Five hundred students (500) were divided into four intermediate-level diploma courses, each with an intensity of 280 hours. 82% (n=411) obtained a certificate of approval, 5% (n=23) obtained a certificate of attendance, 6% (n=30) failed the diploma course, and 7% (n=36) dropped out of the diploma course. In this case, the topic with the highest attrition was video game development, with 10.3% (n=7), and the lowest was UX/UI interfaces, with 5.2% (n=6). It is worth mentioning that in none of the cohorts were differences by genre observed.

## 4 Conclusions

The virtual training program implemented by the National University of Colombia (UNAL) in collaboration with the District Agency for Higher Education (Atenea) significantly impacted ("Todos a La U") the provision of accessible technical training to adult high school graduates in Bogotá.

By deploying a comprehensive student retention strategy focused on data analysis, peer mentoring, psychosocial support, and proactive communication, the program achieved much lower dropout rates (5-9.7%) than the typical 30% attrition in virtual learning environments.

Over 5,000 students were trained across three cohorts in areas such as UI/UX design, mobile app development, digital animation, and video game development. The strategies allowed many of these students to successfully complete the intensive 280-hour basic and intermediate-level programs.

The experience demonstrates the potential of virtual education to provide scalable technical upskilling opportunities, especially when coupled with robust student support mechanisms tailored to the challenges of the online learning format.

From now on, the lessons learned from this initiative can help inform best practices for designing and delivering effective virtual training programs that minimize dropout risks. If replicated across other domains, the strategies used can contribute to bridging digital skill gaps and providing accessible education at scale.

Additionally, the data on factors influencing retention rates in a virtual setting can guide further research into improving online pedagogical models, support interventions, and learning technologies to enhance virtual education outcomes.

Overall, this work highlights a promising approach to leverage the accessibility of virtual learning to impart in-demand technology skills to diverse populations while ensuring high completion rates through a comprehensive student support ecosystem.

The National University of Colombia's virtual training initiative successfully reduced high attrition rates. This was achieved through a comprehensive approach that included data-driven intervention, peer mentorship, psychosocial support, and active communications.

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# Appropriation of the Territory and Active Learning through Environmental Interpretation Walks at the National University of Colombia, Bogotá Campus

Angelica Botello-Yañez[1], Hernán Gustavo-Cortes[2], Eduardo Torres-Rojas[3]

[1, 2, 3] Environmental Management Office1, "National University of Colombia, Bogotá campus, Colombia

Email: rbotelloy@unal.edu.co, hgcortesm@unal.edu.co, edtorresro@unal.edu.co

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**Abstract**

Environmental interpretation tours are spaces that allow the university community to have a direct approach with open ecosystems of active learning and innovation, operating under the conditions and complexities inherent to real life. In this way, individuals within a community not only observe but also participate in all the processes taking place there, from the development of ideas to the implementation of experiments. In the implementation strategy of environmental tours, pedagogical actions will be developed in various environmental themes, with three lines of deepening: comprehensive waste management, fauna, and tree cover. Through the sustainability education and culture program, individuals enjoy and immerse themselves in nature, fauna, and flora through walks and passive recreational activities, without having to travel more than fifteen minutes walking within the walls of the concrete jungle, Bogotá. There they will find savannah snakes, beautiful trees providing a refreshing climate, and the peace and tranquility that nature offers. At the same time, this will generate recognition of different strategic ecosystems, providing sustenance, provision, regulation, and cultural services. By directly experiencing and interacting with them, the community can reflect, acquire knowledge, and understanding through activities facilitating the appropriation of the territory for its use, conservation, and restoration of the university campus. These tours are aimed at an open audience, fostering knowledge, exploration, and dissemination of places with environmental interest. Additionally, they are an open space for environmental volunteering, supporting Environmental School Projects and training processes, which can be developed with all age groups: children, youth, adults, and seniors who are part of the university community.

**Keywords:** Active Learning; Environmental interpretation; Strategic ecosystems; University environmental responsibility; Sustainability; Appropriation of the territory.

## 1 Introduction

Environmental tours are constituted as open ecosystems of learning and innovation, where active participation in all processes reflects the conditions and complexities of real life. In this environment, the community not only observes but also participates from the development of the idea to the execution of experiments. This integral approach is integrated into the strategy of environmental tours, which seeks to promote pedagogical actions in various environmental themes, deepening in three lines from the Education for Sustainability program. One of these lines of action focuses on education and University Environmental Responsibility in the cultural appropriation of sustainability. Here, the aim is to incorporate environmental and sustainability themes into the institutional educational practice through university social responsibility. This involves a commitment to the integral formation of all university actors, from students to administrative staff, in the development of competencies and ethical values in relation to society and the environment.

Environmental interpretation tours are a key tool in this strategy, to foster knowledge, exploration, and dissemination of places with environmental interest. These tours not only provide information about the natural environment but also serve as open spaces for environmental volunteering, support for academic environmental projects, and training processes for all age groups of the university community. Furthermore, for participants to make sense of the information and connect new ideas with their previous knowledge, an active learning approach is required. This process involves reflection, practice, and application of new knowledge and skills to develop a deep and lasting understanding. In contrast to the passive approach, active learning fosters the connection of ideas and creative thinking, fundamental elements in the formation of citizens committed to sustainability (Cortes Mora, University Social Responsibility: A Look at the National University of Colombia, 2012). In this article, we will explore how the integration of environmental tours and the active learning approach contribute to participatory and meaningful environmental education in the university setting.

Figure 1. Image of first semester students on an environmental interpretation tour

## 2 Scope

The scope of this study will encompass a detailed exploration of how the integration of environmental tours and active learning approaches contribute to participatory and meaningful environmental education in the university setting. The conceptualization of environmental tours as open ecosystems of learning and innovation will be examined, where participation reflects the cultural appropriation of University Environmental Responsibility.

This includes the incorporation of environmental and sustainability themes into the institution's educational practice through university environmental responsibility. Additionally, the fundamental role of environmental interpretation tours as a key tool in this strategy will be examined, with a focus on active learning, necessary for the community to make sense of information and connect new ideas with their previous knowledge, contributing to the development of a deep and lasting understanding (Education, Cambridge Assessment International, 2019).The aim is to understand how this approach fosters the connection of ideas and creative thinking in the formation of citizens committed to sustainability.

## 3 Methodology

The methodology employed in this study focuses on the development and implementation of the Education and Culture Plan for Sustainability, aiming to address the environmental issues presented and improve the environmental conditions at the Bogotá campus. This plan aims to formulate new programs and enhance existing ones to enhance human well-being and promote greater university environmental responsibility for the preservation and conservation of the environment on campus and in daily life. It is important to highlight that this educational plan aligns with other guidelines produced by the National Project for Excellence in Environmental Education of the North American Association for Environmental Education, (Ariza & Rueda Toncel, 2016) serving as an integrated sequence of experiences and educational materials designed to achieve specific objectives according to the needs of each institution.

The plan's implementation is carried out through five programs, each with multiple activities that will be conducted both virtually and in person to raise awareness and promote knowledge on environmental issues, covering legislative, procedural, anthropic, and natural components (Yañez, 2021). These activities are designed to provide comprehensive, formal, and non-formal education, allowing the university community to acquire information and knowledge to build sustainable environmental knowledge, values, and practices.

Figure 2. High school students participating in a social cartography activity during an environmental tour

This experience is based on the second line of action of the Education and Culture Plan for Sustainability, namely, Education and University Environmental Responsibility in the cultural appropriation of sustainability, which includes the Environmental Tours strategy with a pilot program consisting of four tours, two natural and two anthropic. These tours are conducted through guided visits around the Bogotá campus, identifying areas of environmental, cultural, historical, and heritage significance, as well as environmental management practices on campus. The tours are available to the university community and various interest groups, such as schools, universities, and the surrounding community, and are conducted during daylight hours. Additionally, requests can be made to the environmental management office to open spaces for these tours during university events or activities. Each tour lasts approximately two hours, during which strategic stops are made to share information and knowledge about environmentally significant areas on campus. Additionally, more specific and complementary activities are conducted, such as observation races and fauna identification events like BioBlitz, (National geographic learning, 2019) where birds are observed and different species of fauna, flora, and trees are identified along with experts in participatory citizen science events.

Promoting learning and autonomy among participants opens up the possibility of becoming more involved in the learning process and having greater control over what they learn, providing them with the necessary skills to promote active learning and develop metacognitive thinking. In this context, various factors come into play, such as the social context, which constitutes a powerful set of forces that influence education, including considerations of ethics, social justice, worldview, freedoms, authorities, power, among others. Within this social context, significant attention is deserved by the governing officials, as elements of social control, who are immersed in these spaces where people from diverse social groups participate and share their different reflections during these events, allowing for the analysis of environmental contexts from different perspectives.

# 4 Results

Within the evidenced results of the impacts and benefits that would arise from the implementation of the Education and Culture Plan for Sustainability at the Bogotá campus, specifically for the environmental tours program, some projected outcomes could include:

- Promoting cultural appropriation in university environmental responsibility: It is expected that carrying out activities such as environmental tours will improve environmental responsibility among members of the university community and other stakeholders, gaining firsthand knowledge of the reality of ecosystems, observing animals, from snakes, birds, and others, that allow attendees to transform their perception about the importance of preserving ecosystems, where at the end of the tours we create spaces for reflection and as a common denominator the community refers to a before and after regarding the perception of their ecosystems.
- Change in environmental practices: Participation in programs and activities related to environmental education is expected to equip participants with knowledge and skills to adopt more sustainable practices in their daily lives and on campus, through active learning, allowing participants to connect with their environment, enabling two elements to mutually enhance each other, providing significant benefits for the physical, cognitive, and emotional development of individuals.
- Development of sustainable skills and values: Participation in formal and informal educational activities will allow participants to acquire knowledge, skills, and values related to sustainability that they can apply in their personal and professional lives, as these tours can show, for example, in the waste collection points, the amount of waste generated by the community, and highlight the work of the center's operators, carrying out waste separation, generating reflections in the participants about the impact, inadequate management, and labor re-signification, as an example of some spaces visited during the tours.
- The impact on the surrounding community: The availability of environmental tours and other activities for the university community and external groups can have a positive impact on the surrounding community by increasing environmental awareness, promoting sustainable practices, and allowing the participation of different social groups and stakeholders that enable the contraction of new knowledge, reflection of ideas, and construction of new knowledge among the participants.

# 5 Discussion

In the discussion of the results obtained from the implementation of the Education and Culture Plan for Sustainability on the Bogotá campus, it is crucial to highlight several key points.Firstly, it is observed that engaging in activities such as environmental tours has had a significant impact on environmental awareness and the promotion of environmental responsibility among university students and other stakeholders. This is evidenced by increased participation in environmental education programs and changes in environmental practices both on campus and in participants' daily lives.

Furthermore, it is noted that the integration of active learning into the plan has significantly contributed to strengthening the university community's commitment to environmental protection. The opportunity to actively participate in the learning process has allowed students to develop practical skills applicable to their daily lives, leading to greater reflection on their role in environmental preservation and the adoption of concrete measures to promote positive change.

Additionally, the positive impact of these educational activities on the surrounding community is emphasized. The availability of environmental tours and other activities has increased environmental awareness in the community and promoted more sustainable practices overall.

In summary, the results of this study suggest that the implementation of the Education and Culture Plan for Sustainability has been effective in promoting greater environmental awareness, fostering environmental responsibility, and strengthening the university community's commitment to environmental protection. The integration of active learning into the plan has been key to achieving these results, providing participants with the opportunity to actively engage in the learning process and develop skills and values related to sustainability

# 6 Conclusion

The implementation of the Education and Culture Plan for Sustainability on the Bogotá campus offers a series of significant impacts and benefits for both the university community and society at large. Through programs such as environmental tours, the aim is not only to promote greater environmental awareness and foster environmental responsibility among university members and other interest groups, but also to promote active learning.

Participation in sustainability-related educational activities provides participants with the opportunity to actively engage in the learning process, allowing them to develop practical and applicable skills in their daily lives. In addition to acquiring knowledge and skills related to sustainability, participants also have the opportunity to reflect on their role in preserving the environment and to take concrete actions to promote positive change.

By integrating active learning into the Education and Culture Plan for Sustainability, the commitment of the university community to environmental protection is further strengthened, and a deeper and more ingrained culture of environmental stewardship is fostered. This approach not only benefits the university and its members, but also has a positive impact on the surrounding community by increasing environmental responsibility and promoting more sustainable practices overall.

In summary, the Education and Culture Plan for Sustainability represents an important step towards building a greener, more responsible university environment committed to preserving the environment and the well-being of future generations, while also promoting active learning and the university community's commitment to environmental sustainability.

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# Transforming the Assessment Method of Multiple Classes: the Case of three Project Management Curricular Units at University of Minho

Anabela P. Tereso [1]

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

Email: anabelat@dps.uminho.pt

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**Abstract**

This paper presents an experience of transforming the assessment method of three curricular units on the subject of project management at the University of Minho, for different engineering courses, Integrated Project Management of the Master in Engineering Project Management and the Master in Chemical and Biological Engineering, and Industrial Project Management of the Master in Industrial Engineering and Management. This experience started with the author's participation in an initiative of IDEA-UMinho Centre to promote teaching and learning, named Assessment+. During the training, several assessment methods were introduced and the participants were asked to analyze a curricular unit and to propose a transformation of the assessment method. The one chosen was Integrated Project Management of the Master in Engineering Project Management. When the next semester started, the proposed transformation was adapted and extended to two more courses with similar contents. Before the transformation, a group assignment to be delivered by the end of the semester, and an individual written test was used for assessment. After the transformation, several group assignments were used, to allow for early feedback. Instead of one individual written test, several individual quizzes were introduced to distribute the learning assessment throughout the semester. A total of 93 students participated in this experience, and 55% answered a questionnaire at the end, used to collect feedback. The main conclusion of this study is that 57% of the students who answered the questionnaire preferred several group assignments during the semester instead of just one to be delivered at the end, and 92% of the students preferred several quizzes throughout the semester. Open questions were also made and the main results are presented in the paper. This experience can serve as a reference for colleagues who want to change their assessment methods to help students have better learning experiences.

**Keywords**: Assessment Methods; Engineering Education; Project Management.

## 1 Introduction

This paper presents an endeavor aimed at transforming the assessment methodology of three distinct curricular units within the field of project management at the University of Minho, offered to various engineering courses. Specifically, it addresses the Integrated Project Management (Int.PM) course within the Master in Engineering Project Management (MEPM) and Master in Chemical and Biological Engineering (MCBE), as well as Industrial Project Management (Ind.PM) course within the Master in Industrial Engineering and Management (MIEM).

This initiative commenced with the author's involvement in a pedagogical endeavor fostered by the IDEA-UMinho Centre, known as Assessment+. During this program, a range of assessment methodologies was introduced, prompting participants to evaluate a specific curricular unit and propose alterations to its assessment approach. The chosen focus was the Int.PM course within the MEPM program. Subsequently, upon the commencement of the subsequent semester, the proposed alterations were adapted and expanded to include two additional courses with similar subject matter.

This transformative experience serves as a resource for colleagues seeking to enhance their assessment methodologies, ultimately aiming to enrich students' learning experiences.

After this introduction (Section 1), a literature review on the topic is presented (Section 2). Section 3 presents the methodology used and section 4 the results obtained and a discussion. Section 5 concludes the paper, section 6 acknowledges the support and section 7 presents the references used.

## 2 Literature Review

Several studies on teaching pedagogy point to the advantages of changing from a traditional teaching paradigm focused on the teacher (traditional lecture method, teaching by telling approach or exposition-centered approach), in which the teacher talks and the students listen, to a teaching paradigm focused on the student and called active learning (or constructivist approach) (Freeman et al., 2014; Handelsman et al., 2004), in which the students, in addition to listening, must also read, write, discuss or get involved in solving problems, thus promoting their capacity for analysis, synthesis and evaluation (Bonwell & Eison, 1991).

To be successful in preparing our students for the future, the authors Wallner et al. (2016) suggest considering the following: enable and support our students' ability to self-organize; future challenges are increasingly interdisciplinary; individual learning processes require individual assessments; we are not the only holders of knowledge, the information our students need is abundant and available everywhere; transforming the available information into useful individual knowledge requires meta-knowledge and methodological skills, our experience enables us to help our students in this process; learning should be seen as a joint activity. We have to open up our universities and invite students to use this space as a place for meetings and discussion. We have to create the right social settings where students can discuss and work on real-life problems, which are preferably directly related to the world they live in.

Puncreobutr (2016) lists what he considers to be the key skills for the Education 4.0 era. In addition to the 21st century skills (leadership, collaboration, creativity, digital literacy, effective communication, emotional intelligence, entrepreneurship, global citizenship, problem-solving skills and teamwork), he also list the skills that make it possible to build smart nations or smart people with critical thinking, such as creativity and innovation, intercultural understanding, media and information literacy and, finally, career and apprenticeship skills. These can give us some clues as to the skills we need to help develop in our students.

To develop these skills we can use methods such as (Puncreobutr, 2016): organizing the learning process in real contexts (Zhao, 2012); organizing teaching in 4 different ways, 1) based on critique, 2) based on creativity, 3) based on productivity, and 4) based on responsibility (Sinlarat, 2016); use constructivist learning, based on the 3R, 3I and 3P phases, 3R is related to regulating understanding, which consists of Recall, Relate, Refine, 3I is related to investigating and consists of Inquire, Interact, Interpret, and 3P is related to producing, creating work by Participating, Processing and Presenting (Gomaratat, 2015); using social & virtual learning, learning based on social media, in large groups and in a virtual environment (Jeschke & Heinze, 2014).

Some tools that can be used now or in the near future are also mentioned: visual learning, social media, game-based learning, connectivity, project-based learning, mobile technologies, among others (Puncreobutr, 2016).

Evans (2013) presented a study concerning assessment feedback in higher education (HE). Through an exhaustive literature review, the concept of the feedback landscape, influenced by sociocultural and socio-critical perspectives, is formulated and presented as a framework for assessment feedback in HE. The feedback landscape focuses on process and individual development from both student and lecturer perspectives. Feedback can be perceived either as a consequence of performance or as an integral part of the learning process, fostering continuous improvement and future learning. Additionally, assessment feedback can be motivational, reinforcing, or informational, aiming to enhance performance and facilitate knowledge transfer. Feedback plays a crucial role in HE, aiding students in becoming independent learners and shaping their professional identities. It can be done in different ways, like electronic assessment feedback (EAF), self-assessment feedback, and peer assessment feedback. EAF, delivered through various digital technologies, is praised for its potential to deepen learning approaches and enhance student achievement, although its impact on student engagement and performance varies. Self-assessment feedback is considered vital for promoting self-regulation, but there are challenges in developing students' self-assessment skills effectively. Peer assessment feedback is seen as motivational and conducive to metacognitive development, although its benefits can be variable and depend on factors such as student readiness and the quality of feedback provided. Training in the use of feedback methods, ongoing support, and alignment with learning objectives are highlighted as crucial elements for maximizing the effectiveness of these feedback approaches.

Pereira et al. (2016) reviewed research on assessment and evaluation in higher education, identifying several methods including examinations, multiple-choice tests, coursework, portfolios, digital and paper diaries, group summative assessments, oral presentations, and written assessments. Their findings indicated that most studies emphasize portfolio assessment, followed by written exams, oral exams, group assessments, and both paper and digital diaries. In terms of assessment modes, the majority of research focuses on self- and peer-assessment, followed by formative, continuous, and summative assessments. When examining assessment for specific teaching and learning methods, studies primarily address portfolio assessment, group work assessment, problem-solving and project-led education, alternative assessment methods, and online environments. The researchers concluded that students benefit from a variety of assessment practices beyond traditional written tests.

# 3 Methodology

The methodology used for this study was multiple case study. The focus was in three project management curricular units at University of Minho, namely Int.PM of the MEPM and the MQBE, and Ind.PM of the MIEM. After the author's participation in Assessment+, an initiative of IDEA-UMinho Centre to promote teaching and learning, a proposal of transforming the assessment method was made and in the next semester, implemented in these three cases. At the beginning of the semester the students were informed that this was an experience aiming to access if changing the assessment method was positive to the students, and that at the end of the semester they would answer a questionnaire concerning the assessment methods and their opinion on the change.

Prior to the transformation, assessment primarily relied on a single group assignment due at the semester's conclusion, alongside an individual written examination. Post-transformation, a series of group assignments were implemented to facilitate early feedback mechanisms. Furthermore, the traditional singular written test was replaced with multiple individual quizzes distributed throughout the semester.

In the Int.PM course, for the MEPM and the MQBE, the weight of the group assignments was 60%, and the weight of the individual quizzes was 40%. The group assignments for the MQBE were 3 presentations, a project management simulation game, and a final delivery assignment, and for the MEPM there was one more presentation, the rest being the same. As for the individual quizzes, there were 4 in both programs.

In the Ind.PM course, for the MIEM, the weight of the group assignments was 75%, and the weight of the individual quizzes was 25%. The group assignments included 7 deliverables (including 2 presentations) and the individual assessment included 3 quizzes.

The structure of the questionnaire was the same for the three courses, except for question 5, that was only made to MEPM and MQBE.

It included the following multiple-choice questions:

1. I prefer group work:
   a. With a presentation and a final delivery.
   b. With presentations and deliveries throughout the semester.
2. I prefer individual assessment:
   a. With several quizzes throughout the semester.
   b. In a single final test.

And the following open-ended questions:

3. Comments on how the group work went (what went well/bad, different suggestions).
4. Comments on how the quizzes went (what went well/poorly, different suggestions).
5. What is your opinion of the class with the Project Management Simulator? (only for MEPM and MQBE).
6. What is your general opinion of Int.PM/Ind.PM?
7. What is your opinion about the teacher?
8. Suggestions for improvement.

A cohort of 93 students partook in this initiative, with 55% of them (51 students) providing feedback through a post-experience questionnaire. The feedback was anonymous.

# 4 Results and Discussion

The primary findings of this study indicates that 57% of respondents favored the incorporation of multiple group assignments throughout the semester as opposed to a single assignment at the term's end. Additionally, an overwhelming 92% of students expressed a preference for the integration of several quizzes distributed across the semester to assess learning progress (see results in Figure 1). These are the results of questions 1 and 2 (see section 3).

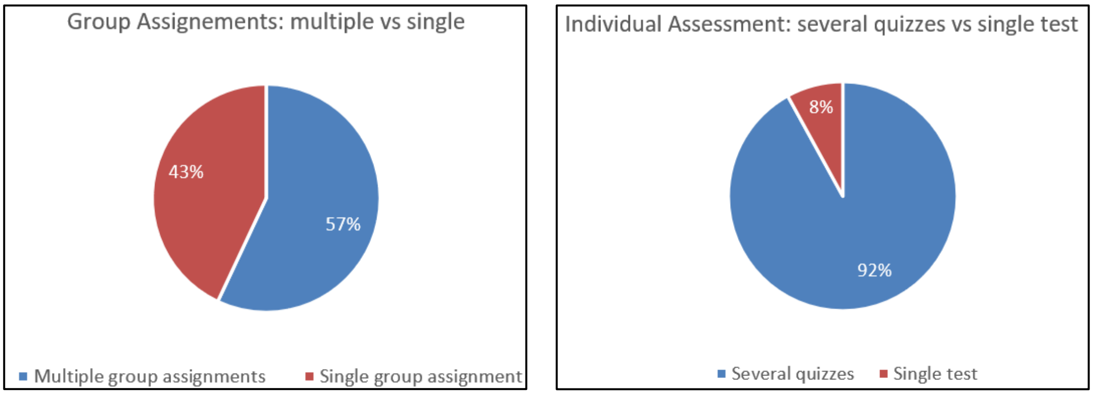


Figure 1. Results for the results preferences concerning group assignments and individual assessment

Open-ended questions were also administered, yielding further insights.

As for the comments on how the group work went, of the 51 students that answered, 2 considered it went very well, 26 considered it went well, 2 considered it went normally and 21 reported different opinions and some difficulties. Some of the comments of the students were: “I think the group work went very well, all the members carried out the assigned tasks and there was a lot of mutual help”; “I really liked the assessment methodology used, I believe that with assignments over the course of the semester, you learn more than a final assignment, in other words, students will be more involved in the content covered”; “The group work went well, the presentations distributed in this way helped us to always understand the doubts of the moment and helped us to assimilate the information from one week to the next”; “I think it went well, as we did throughout the semester, I felt that the workload wasn't too much and I was able to clear up any doubts, honestly, I liked it”; “I found it challenging and it promoted autonomy and self-learning"; "Unfortunately, we don't always contribute in the same way and with the same commitment to the work, but I still think the balance is positive"; "I think the number of papers and presentations should be reduced, I would suggest only 1 intermediate presentation"; "We had some problems using the software"; "Often the work is so presentation-oriented that the knowledge, the learning, the work done by the groups is no longer assessed, but rather the way things are presented and the ability of the groups to do so, which is also important, but which creates alienation from the course content". The opinions expressed in this question were in majority positive and reinforce that the use of several group assignments as positive, although some difficulties have been pointed out.

As for the comments on how the quizzes went, of the 51 students that answered, 3 considered it went very well, 28 considered it went well, 3 considered it went normally and 17 reported different opinions and some difficulties. Some of the comments of the students were: "In my opinion, it was the part of the course that went best, the fact that we have to study systematically helps us learn"; "I think that the division of the quizzes went very well, it makes it easier for the students to learn and understand the content taught"; "It's a good idea to separate them into parts so that you can go deeper into each topic"; "The quizzes were interesting, as a single test would have been too heavy in terms of content"; "They allowed us to have knowledge and continuous study of the subject taught"; "I think it went well, in the sense that the teacher was always very understanding and flexible when it came to resolving possible setbacks and technical difficulties"; "The first quiz was difficult by the fact that it was quite theoretical, but the others were ok"; "It should be possible to skip questions and come back to them later"; "I suggest not waiting for the late students to arrive... when the planned time arrives, the quiz should begin"; "As a working student not all of them went well for me because of certain doubts I had when I wasn't at the beginning of the lesson, and studying on my own wasn't always successful"; "Some quizzes were too long, so I'd prefer just one final test with 2 hours, for example"; "The teacher could have made the correction of each quiz available". These results reinforce that several quizzes is better than one test at the final of the semester. These quizzes were made via Blackboard, and some technical difficulties were reported, but generally they went well.

The class with the Project Management Simulator was only for MEPM and MQBE students, and there were 33 answers. Some of the most representative answers were: "An interesting class that allowed us to put our knowledge into practice"; "Dynamic lessons and a fun way to learn"; "Interesting tool for understanding the work routines of project managers"; "I got a sense of what's yet to come on a professional level"; "Good for growing group spirit and time management"; "It was really fun and educational"; "A different, more dynamic lesson that helped to understand the various concepts"; "I liked it! It was something different from what I've done at any other curricular unit"; "It was fun, but because the time was short, some details were missed"; "Very interesting, I would have liked to learn more about the tool". The feedback concerning the project management simulator was really good, so it will be a practice to keep.

Concerning the question about the general opinion about the course Int.PM/Ind.PM, some of the most representative answers were: "A very enriching curricular unit"; "Very interesting course with a practical project management component throughout the semester"; "Subject that covers relevant concepts"; "In all areas of life there are projects, so it's important to be aware of how to manage a project"; "I really enjoyed it; it was my favorite course from the beginning to the end of the semester, I think I learned a lot in this course and project management has become my main area of interest for the job market"; "The course was interesting because of its scope and the fact that we had never had anything like it before, continuous assessment led to better performance"; "It's an interesting and useful topic for carrying out and managing future projects, essential for successfully achieving your goals"; "I think it was an interesting subject, and it allowed me to get to know the reality of project management and how complex this world is"; "I liked it, even though it was a bit of a challenge and always required a lot of commitment"; "It's a complex subject, with many new concepts, but very pertinent since it's a cross-cutting theme in any work environment, it was interesting to get a deeper insight into the topics covered, it's certainly a professional reality in our area, so I think it was very enlightening and motivating"; "I found it an interesting course and the information I learned is easily applicable, from the most basic day-to-day tasks to university and work projects"; "Before this course, I had never talked about many concepts or ways of managing a team, I thought it was an interesting subject and different from what I usually do in my program, so I felt it was an asset, I especially liked the more dynamic classes, doing group tasks"; "Interesting curricular unit, but a little complex to be given in one semester"; "I liked the course, it was interesting, but because of all the presentations and quizzes it was very hard work". The feedback relating the course was really good, and this feedback an incentive to continue improving in the future.

The most representative answers related to the opinion about the teacher where the following: "Very helpful and an excellent professional"; "Always willing to help and advice in the best way"; "Dynamic way to taught the students"; "A competent professional with a great deal of knowledge of the subject"; "Explains quite well"; "Very attentive and concerned about the students"; "The teacher proved to be an excellent professional in terms of her commitment to teaching the content, but also in monitoring the students"; "Friendly, concerned about the students, attentive and above all the availability she offers"; "Excellent, very good and interactive tutor"; "She is respectful, attentive, available and committed to the best for her students"; "Very helpful, always responded very quickly and always helped"; "The teacher was always willing to help the groups, and the feedback was always very constructive, in addition, the teacher was always very attentive"; "I thought the teacher conveyed the subject well, emphasized what was most important and managed to make a group that had no contact with project management understand this complex work"; "It was a pleasure to be your student and learn from your experience! I like the atmosphere you create in the classroom, because it makes the students more comfortable (even to make mistakes), and the presentation moments are more like learning moments"; "Your interest in the subject stimulates the students' interest"; "Teacher concerned about the students, however, the lessons were sometimes monotonous"; "She was very attentive to the mistakes made in the assignments"; "Sometimes she gives unobjective information". Concerning this feedback, I can reinforce that it is a pleasure to teach these courses, to these students. All the opinions are important, but it is good to know that the majority of them are very positive. The less positive ones are also important to encourage improvement.

Finally, suggestions for improvement were required to the students. Nothing to point out or I was satisfied was the response of 8 students. Some of the other most representative answers were: "More exercises solved in class"; "Assessment in a final test only"; "There are a lot of assignments, especially for working students, and this can make it very difficult to continue in the Master's program"; "Greater support in the use of the project software tool"; "Decrease the time of the quizzes or have only one final test"; "Make the corrected quizzes available and perhaps reduce the number of presentations, considering only the delivery of the work"; "Perhaps fewer presentations"; "I support the idea of continuous work, but maybe I'd like it better if the presentations were every two weeks... that would help the students lighten their workload"; "Slides in Portuguese; it's easier to study"; "I would just suggest that, at the end of some lessons, we spend a bit of time getting to grips with the project software in the classroom"; "In my view, the evaluation of this course is very fair given the complexity of the concepts"; "Some classes should be more dynamic"; "Dividing the assessment of the course into many assignments and tests can be positive, as long as the time needed to complete them is related to the final percentage of the course grade. I felt that throughout the semester the total number of hours spent on this subject was much higher than any other subject, because each assessment required a lot of time, especially the presentations, for too small a percentage of the final grade". These final suggestions have very important information that may help to improve even more in the future.

Considering all the results obtained, transforming the assessment method in these three project management courses at the University of Minho—specifically changing a single group assignment at the end of the semester into multiple group assignments and a single final test into several quizzes—proved to be well received by the majority of students and increased satisfaction. However, some students felt it was too much work. Therefore, an intermediate solution, balancing one test and one group assignment with several quizzes and group assignments, could be more effective and will be tested in the future. The project management simulation game was particularly well received by students, and thus, it will continue to be used.

# 5 Conclusion

This paper describes the transformation of assessment methods for three curricular units focused on project management at the University of Minho. The author participated in the Assessment+ initiative, where various assessment methods were introduced. The chosen transformation was implemented in the Integrated Project Management course of the Master in Engineering Project Management and later extended to two other courses with similar content. Before the transformation, assessment relied on a final group assignment and an individual written test. After the transformation, multiple group assignments were introduced to allow for early feedback, and individual quizzes were spread throughout the semester. Feedback from 93 participating students revealed a preference for multiple group assignments (57%) and multiple quizzes (92%) throughout the semester. The paper provides insights and results from this experience, offering a model for colleagues seeking to improve their assessment methods to enhance student learning experiences.

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# Prediction of Academic Performance by Measuring Autonomy for Learning in an Engineering Program

Leonidas Sandoval[1], Fabio Orfali[1]

[1] Insper – Instituto de Ensino e Pesquisa, São Paulo, Brazil

Email: leonidassj@insper.edu.br, fabioo1@insper.edu.br

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**Abstract**

We applied a test that maps 10 distinct aspects of Autonomy for Learning to 69 students entering Engineering programs in a school of Engineering and then followed that group into their first two semesters. The test was LASSI, Learning Strategies Inventory, used by hundreds of institutions around the world in order to detect and provide advice to students that might show deficiencies in their learning strategies. The aspects are Anxiety, Attitude, Concentration, Information Processing, Motivation, Selecting Main Ideas, Self-testing, Assessment Strategy, Time Management and Use of Academic Resources. We analyzed how each of the 10 aspects, all considered important to the development of students in higher education, impacted on their academic performance as measured by their final grades in 10 courses of their first two semesters in Engineering. Those final grades are the results of a series of assessments, ranging from written exams to activities in class and to projects, varying from course to course. Pearson correlation was used as the main tool in studying how the aspects measured by LASSI are related with those final grades. Results revealed correlations above the noise level for the aspects Concentration and Motivation and the grades obtained, mainly in STEM (quantitative) courses. These findings provide insights into identifying the key aspects of learning strategies that should be fostered among students in Engineering programs to enhance academic performance.

**Keywords**: Autonomy for Learning; Engineering Education; Learning Strategies; Correlation.

## 1 Introduction

Academic success of students stands as a pivotal variable for any higher education institution, often serving as a metric for institutional performance (Alyahyan & Düstegör, 2020) and directly linked to dropout rates, a phenomenon imposing significant financial losses on universities (Gallego, Cobos & Gallego, 2021). Thus, the investigation of factors predicting or influencing academic performance of higher education students has emerged as an important research agenda at the intersection of psychological sciences and education (Costa & Fleith, 2019).

Before presenting the factors that have been considered relevant to the academic success of higher education students, it is important to make a remark. According to York, Gibson & Rankin (2015), the term academic success has appeared in various research studies as an amorphous construct, encompassing educational outcomes ranging from degree attainment to students' moral development. Thus, it is crucial to clarify what is considered academic success in this study, which will be addressed in the following sections.

O'Connor & Paunonen (2007) suggest that intelligence is not the best predictor for the performance of higher education students. This finding, corroborated by two other studies (Busato et al., 2000, and Resing & Drenth, 2007), may be explained by the fact that university entrants are predominantly selected based on intelligence. Thus, other aspects become necessary to predict academic performance.

Besides intelligence, other factors have proven relevant to academic performance in higher education courses: students' personality (Kappe & Van der Flier, 2012), their motivation and study habits (O'Connor & Paunonen, 2007), sociodemographic characteristics (Helal et al., 2018), and the students' environment, described as class type, semester duration and type of program (Hamoud, Hashim & Awadh, 2018). Among these factors, we will describe some results obtained in studies on the different personality traits of students, as they may be related to the aspects of autonomy for learning investigated in this research.

The primary theoretical model used to analyse the influence of personality traits on academic success is the Five-Factor Model of personality (O'Connor & Paunonen, 2007; Mammadov, 2021). According to the model, the five major personality factors - Neuroticism, Extraversion, Openness to Experience, Agreeableness, and Conscientiousness - constitute the highest level of the personality hierarchy. Thus, they encompass all other possible personality traits, which are found at a lower level of hierarchy.

Among the Big Five factors, Conscientiousness has been consistently associated with post-secondary academic success. Several studies have identified positive correlations between this factor and various indicators of academic performance such as GPA (Grade Point Average – the weighted average of the grades for each course in the program). According to O'Connor & Paunonen (2007), "the relation between Conscientiousness and academic performance has often been interpreted in terms of motivation; conscientious students are thought to be more motivated to perform well academically than are less conscientious students". Apparently, the ability to focus on a task in an organized and results-oriented manner, which characterizes Conscientiousness, tends to lead to better academic performance.

Considering this scenario, this study investigated possible correlations between 10 different aspects related to students' autonomy for learning and their academic performance in the first year of an Engineering program.

## 2 Data

We use three sets of data, collected from LASSI (Weinstein, Palmer, Acee, 2016) and from the final grades of 69 students of the Engineering courses at Insper, an institution for higher learning located in São Paulo, Brazil. Those students were the ones that took the LASSI at entrance in college in February 2023, concluded the first semester in June 2023 and the second semester in November 2023. All students entering Insper in that semester took the test, via an online set of questions. About 300 students took the test, including Business and Administration, Economics, Engineering, Law, and Computer Science, but we included in our research only those students that finished the first and second semesters in Engineering (Mechanics, Mechatronics and Computer Engineering).

LASSI measures 10 aspects that are deemed important for the Autonomy of Learning (Weinstein, Palmer, Acee, 2016). We briefly describe these aspects in what follows.

- **Anxiety.** The tension or worriedness of a student when approaching academic tasks.
- **Attitude.** Ability to act based on interests and reasons for succeeding in academic life.
- **Concentration.** Ability to direct and maintain attention to academic activities.
- **Information Processing.** Student can create means to promote understanding and recall.
- **Motivation.** Student accepts responsibility for conducting tasks related to academic success.
- **Selecting Main Ideas.** Ability to extract meaningful information from text or data.
- **Self-testing.** Ability to ask questions that help revise and review topics for activities or exams.
- **Test Strategies.** Ability to use strategies and of taking and preparing for exams or assignments.
- **Time Management.** Student develops methods for the organization of study.
- **Using Academic Resources.** Knowledge or willingness to look for and use academic resources provided by the institution.

The grades obtained in the ten aspects measured by LASSI were compared to the final grades of ten course units, taken in the first and second semesters of Engineering at Insper. Those course units are described briefly now.

**First Semester**

- **Software Design.** Fundamentals of programming and algorithms.
- **Grand Challenges of Engineering.** Relationships between science, society, and ethics.
- **Instrumentation and Measurement.** Use of tools for measuring and of measuring techniques.
- **Modelling and Simulation of the Physical World.** Mathematical and numerical modelling and simulation of dynamic systems.
- **Design Nature.** Design, prototyping, and fabrication of a product.

**Second Semester**

- **Activation of Electric Systems.** Concepts, components, and workings of an electric circuit.
- **Data Science.** Statistics and probability.
- **Co-Design of Apps.** User-oriented design and production of software.
- **Physics of Movement.** Cinematics and dynamics of moving bodies.
- **Mathematics of Variation.** Limits, derivative, and integrals of functions of one variable. Differential equations and Linear Algebra.

# 3 Methodology

To assess the relation between Autonomy for Learning and academic performance for the two first semesters of the Engineering course, we use the Pearson correlation coefficient, defined in the following way for two variables $x$ and $y$, with $n$ measures $x_i$ and $y_i$, $i = 1, \dots, n$:

$$\rho = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - y)^2}} , \tag{1}$$

where $\bar{x}$ is the average of $x$ and $\bar{y}$ is the average of $y$. The Pearson correlation is used to measure the linear correlation between two variables. In our set of data, when calculating the Pearson coefficient between LASSI and grades, $x_i$ are the LASSI score for each student in the sample for a particular aspect of autonomy for learning, and $y_i$ is the final grade obtained by the same student in a certain course unit. In order to visualize the results, we also use a network representation based on asset trees, by selecting only connections that are above a certain threshold. We also use a centrality measure to classify results by this criterium.

# 4 Results

In what follows, we shall adopt the following indices for the variables being measured, as shown in Table 1.

Table 1. Variables and indices.

| **Aspects of the LASSI** | | **Course Units** | |
|---|---|---|---|
| Anxiety | 1 | Software Design | A |
| Attitude | 2 | Grand Challenges of Engineering | B |
| Concentration | 3 | Measuring and Instrumentation | C |
| Information Processing | 4 | Modelling and Simulation of the Physical World | D |
| Motivation | 5 | Design Nature | E |
| Selecting Main Ideas | 6 | Activation of Electric Systems | F |
| Self-testing | 7 | Data Science | G |
| Test Strategies | 8 | Co-Design of Apps | H |
| Time Management | 9 | Physics of Movement | I |
| Using Academic Resources | 10 | Mathematics of Variation | J |

We first discuss the correlation between the ten aspects of Autonomy for Learning measured by LASSI. Below, we show the correlation matrix between these variables (Table 2), highlighting the ones above correlation 0.4 and those above correlation 0.3. Reminding ourselves that this is a symmetric matrix, and thus one that shows the same information twice, we only highlight the values below the main diagonal.

Most correlations above 0.2 are considered to convey meaningful information about how correlated two aspects are to one another. Results seem to show stronger correlations between Attitude and Concentration to many of the other aspects. Selecting Main Ideas and Time management also appear as having stronger correlations with some of the other aspects measured by LASSI.

Table 2. Correlation between aspects of the LASSI.

| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 1,00 | 0,16 | 0,31 | 0,02 | -0,10 | 0,45 | -0,21 | 0,25 | 0,02 | 0,05 |
| **2** | 0,16 | 1,00 | 0,43 | 0,26 | 0,49 | 0,39 | 0,21 | 0,22 | 0,46 | 0,29 |
| **3** | **0,31** | **0,43** | 1,00 | 0,10 | 0,43 | 0,43 | 0,11 | 0,41 | 0,56 | 0,01 |
| **4** | 0,02 | 0,26 | 0,10 | 1,00 | 0,24 | 0,21 | 0,40 | 0,03 | 0,19 | 0,46 |
| **5** | -0,10 | **0,49** | **0,43** | 0,24 | 1,00 | 0,30 | 0,35 | 0,27 | 0,44 | 0,27 |
| **6** | **0,45** | **0,39** | **0,43** | 0,21 | **0,30** | 1,00 | 0,11 | 0,47 | 0,34 | 0,23 |
| **7** | -0,21 | 0,21 | 0,11 | **0,40** | **0,35** | 0,11 | 1,00 | 0,11 | 0,22 | 0,25 |
| **8** | 0,25 | 0,22 | **0,41** | 0,03 | 0,27 | **0,47** | 0,11 | 1,00 | 0,32 | 0,05 |
| **9** | 0,02 | **0,46** | **0,56** | 0,19 | **0,44** | **0,34** | 0,22 | **0,32** | 1,00 | 0,18 |
| **10** | 0,05 | 0,29 | 0,01 | **0,46** | 0,27 | 0,23 | 0,25 | 0,05 | 0,18 | 1,00 |

We now look at the correlations of the 10 course units of the first and second semester (Table 3). Again, we highlighted higher correlations only for the data below the main diagonal of the matrix.

Table 3. Correlation between course units.

| | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** |
|---|---|---|---|---|---|---|---|---|---|---|
| **A** | 1,00 | 0,34 | 0,63 | 0,52 | 0,05 | 0,43 | 0,49 | 0,31 | 0,60 | 0,61 |
| **B** | **0,34** | 1,00 | 0,38 | 0,46 | 0,10 | 0,18 | 0,45 | 0,30 | 0,28 | 0,33 |
| **C** | **0,63** | **0,38** | 1,00 | 0,42 | 0,25 | 0,54 | 0,65 | 0,38 | 0,73 | 0,67 |
| **D** | **0,52** | **0,46** | **0,42** | 1,00 | 0,15 | 0,30 | 0,51 | 0,29 | 0,49 | 0,55 |
| **E** | 0,05 | 0,10 | 0,25 | 0,15 | 1,00 | 0,22 | 0,22 | 0,36 | 0,14 | 0,19 |
| **F** | **0,43** | 0,18 | **0,54** | **0,30** | 0,22 | 1,00 | 0,60 | 0,29 | 0,65 | 0,60 |
| **G** | **0,49** | **0,45** | **0,65** | **0,51** | 0,22 | **0,60** | 1,00 | 0,40 | 0,69 | 0,67 |
| **H** | **0,31** | **0,30** | **0,38** | 0,29 | **0,36** | 0,29 | **0,40** | 1,00 | 0,27 | 0,41 |
| **I** | **0,60** | 0,28 | **0,73** | **0,49** | 0,14 | **0,65** | **0,69** | 0,27 | 1,00 | 0,84 |
| **J** | **0,61** | **0,33** | **0,67** | **0,55** | 0,19 | **0,60** | **0,67** | **0,41** | **0,84** | 1,00 |

The first five course units are of the first semester of the Engineering program and the last five are of the second semester. Results show the average of the correlations of the final grades of students in a course unit compared with the final grades of the same students in another course unit. Correlations are now, in average, higher than the ones between aspects of the LASSI.

Looking at correlations within the first semester (top left sector of the matrix), one finds strong correlations between final grades of Software Design and Modelling and Simulation of the Physical World and other course units where Mathematics is important. There is less correlation of course units where Mathematics is not necessarily present.

Correlations between course units of the second semester (bottom right sector of the matrix) are generally stronger, except for Co-Design of Apps, where Mathematics is not central. Note the very strong correlation of grades obtained in Physics of Movement and Mathematics of Variation.

Looking at the correlations between course units of different semesters, bottom left sector of the matrix, one can see strong correlations between Physics of Movement with Software Design and with Measuring and Instrumentation, and between Mathematics of Variation and those same course units. There are strong correlations between other inter-semester course units, except with Design Nature.

We now turn to the main concern of this article, which is to study the correlations between aspects of the LASSI and course units (Table 4). Now the correlation matrix is asymmetric and so we highlight higher values in the whole matrix. We also highlight meaningful negative correlations, those that are below what is expected for random data. Sectors divide course units of the first and second semesters.

Table 4. Correlation between aspects of the LASSI and course units.

| | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 0,14 | 0,14 | -0,03 | 0,13 | -0,15 | -0,06 | -0,02 | -0,01 | 0,01 | -0,08 |
| **2** | 0,18 | **0,20** | **0,21** | 0,13 | 0,18 | -0,02 | 0,15 | -0,09 | 0,14 | 0,14 |
| **3** | **0,33** | **0,27** | **0,37** | **0,41** | **0,21** | 0,06 | 0,19 | -0,11 | **0,37** | **0,22** |
| **4** | -0,01 | 0,02 | -0,04 | -0,10 | -0,01 | -0,18 | 0,03 | -0,01 | -0,11 | -0,03 |
| **5** | **0,22** | **0,25** | **0,22** | **0,22** | 0,12 | 0,12 | 0,17 | **-0,24** | **0,21** | **0,20** |
| **6** | 0,14 | **0,24** | 0,03 | 0,06 | -0,06 | 0,11 | 0,06 | -0,13 | 0,10 | -0,03 |
| **7** | -0,17 | 0,05 | -0,09 | -0,04 | 0,07 | **-0,20** | **-0,29** | -0,18 | **-0,29** | -0,16 |
| **8** | 0,09 | **0,33** | 0,15 | **0,31** | 0,09 | 0,13 | 0,16 | 0,00 | 0,08 | 0,11 |
| **9** | 0,18 | **0,20** | **0,23** | **0,24** | **0,24** | 0,05 | 0,02 | -0,14 | 0,13 | 0,13 |
| **10** | -0,07 | 0,03 | -0,17 | **-0,22** | -0,13 | -0,01 | -0,04 | -0,08 | -0,02 | 0,03 |

Correlations now have smaller values, even meaningful negative ones. Correlations above 0.3 can be found between Concentration and Software Design, Measuring and Instrumentation, Modelling and Simulation of the Physical World, and Physics of Movement. Other correlations above 0.3 appear between Test Strategies and Grand Challenges of Engineering and Modelling and Simulation of the Physical World. There are also some meaningful anticorrelations between Self-testing and some course units of the second semester. Course units that are most correlated with the aspects measured by LASSI are Grand Challenges of Engineering and Modelling and Simulation of the Physical World. Co-Design of Apps is weakly negatively correlated with most aspects of the LASSI.

What we may conclude from the data collected and analysed is that Concentration seems to be correlated with grades obtained in some course units of the first semester, and that this correlation weakens for course units of the second semester, except for Physics of Movement and, to a lesser extent, to Mathematics of Variation.

# 5 Network Structure

Another way to visualize this data is to use networks, which are basically a number of nodes (usually represented by dots) connected by edges (Newman, 2010). In the case of the present work, each dot is an aspect of Autonomy for Learning measured by LASSI (red dots) or a course unit (blue dots for first semester and purple dots for second semester). Edges are given by the correlation between nodes. Since correlation is symmetric, edges are undirected. A network can be built by using thresholds, which are values of correlation above which edges are represented, with the omission of edges below the threshold value and of those nodes without any edges. This is usually called an asset graph (Onnela et al, 2003).

Figure 1 shows the asset trees resulting from choosing thresholds of correlation above 0.8, above 0.7 and above 0.6. Note that the only correlations above those threshold values are ones between course units.

Figure 2 shows the asset trees resulting from choosing threshold 0.5. One may see now the first connection between aspects of the LASSI, between Concentration and Time Management, and an intensification of connections between many of the course units.

At the edge of noise level, which is about correlations below 0.3, we have the asset graph for threshold 0.4 (figure 3), where there are clearly two clusters, one of aspects of the LASSI, and another of course units. One may also see the first connection between both clusters, between Concentration and Modelling and Simulation of the Physical World. Other asset trees, below threshold 0.3, not shown here, also describe two clusters, with increasing connections among their members, and also an increase in connections between clusters.

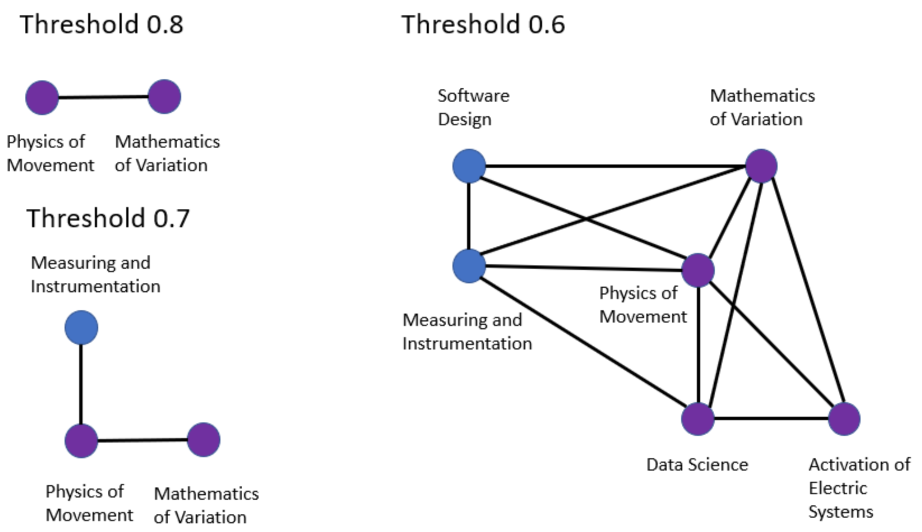


Figure 1. Asset graphs of course units with correlation thresholds above 0.8, above 0.7 and above 0.6

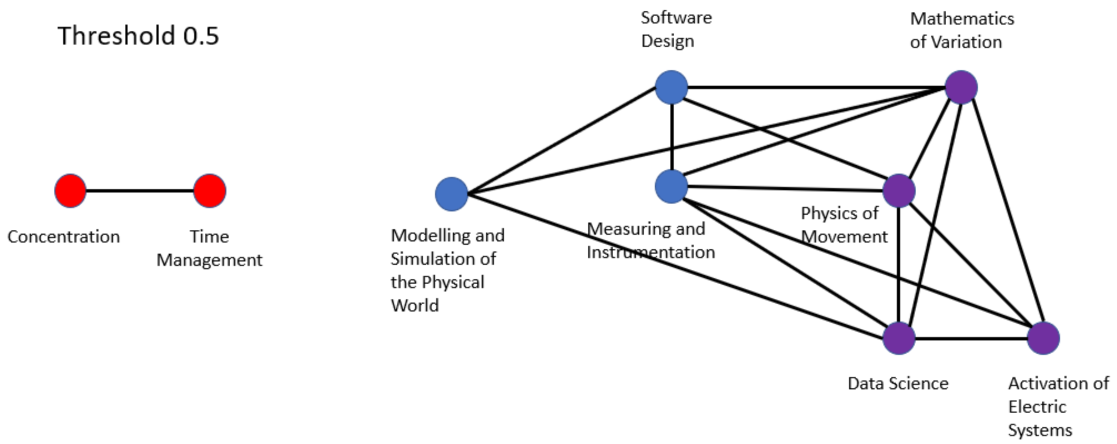


Figure 2. Asset graph for threshold 0.5

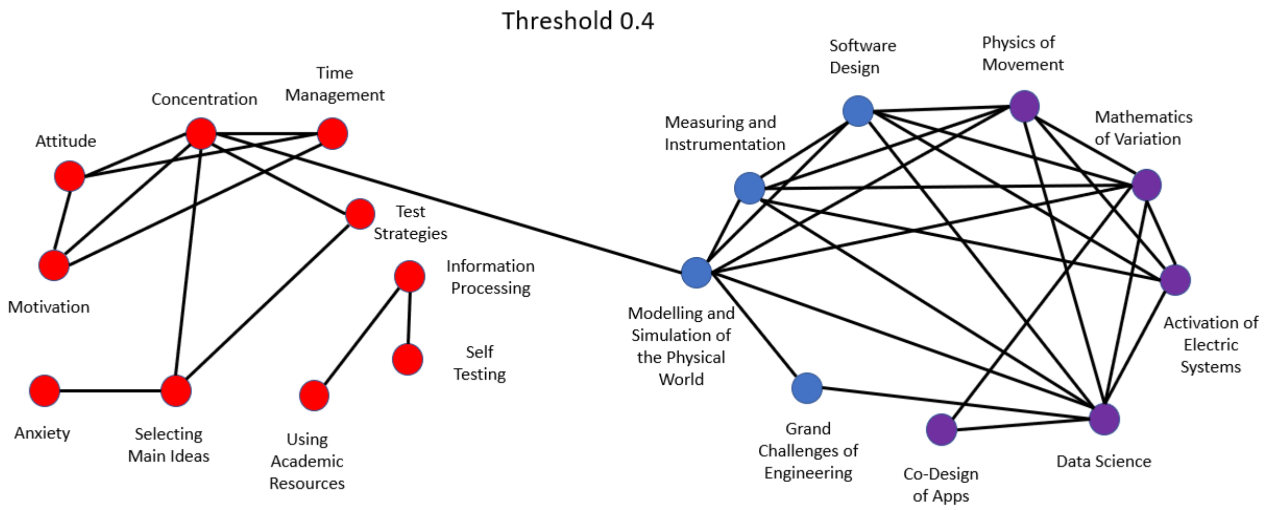


Figure 3. Asset graph for threshold 0.4

At the cluster of aspects of the LASSI, we may identify a tighter clustering between what are aspects related with Resilience or Conscientiousness, namely Concentration, Attitude, Time Management, and Motivation. At lower values of the threshold, this subcluster connects with performance in course units. One measure of how central a node is in a network is Node Degree (Newman, 2010), which is the number of edges of a certain node, but this depends on the choice of threshold. Another measure is Node Strength, which is the sum of the weights of edges connected to a node. In the case of correlation matrices, it is the sum of the line of a matrix, or of the column, related with a node. Table 5 shows the Node Strengths of each of the nodes in our network, subdivided by correlation matrix. The first subdivision is between aspects of the LASSI with themselves. Selecting Main Ideas, Attitude, Concentration, Time Management, and Motivation appear as strongly connected in that cluster.

Table 5. Node strengths ordered.

| **LASSI - LASSI** | |
|---|---|
| **Aspects of the LASSI** | **NS** |
| Selecting Main Ideas | 2,93 |
| Attitude | 2,91 |
| Concentration | 2,79 |
| Time Management | 2,73 |
| Motivation | 2,69 |
| Test Strategies | 2,13 |
| Information Processing | 1,91 |
| Using Academic Resources | 1,79 |
| Self-testing | 1,55 |
| Anxiety | 0,95 |
| **LASSI - Course Units** | |
| **Aspects of the LASSI** | **NS** |
| Concentration | 2,32 |
| Motivation | 1,49 |
| Test Strategies | 1,45 |
| Time Management | 1,28 |
| Attitude | 1,22 |
| Selecting Main Ideas | 0,52 |
| Anxiety | 0,07 |
| Information Processing | -0,44 |
| Using Academic Resources | -0,68 |
| Self-testing | -1,3 |

| **Course Units - Course Units** | |
|---|---|
| **Course Units** | **NS** |
| Mathematics of Variation | 4,87 |
| Physics of Movement | 4,69 |
| Data Science | 4,68 |
| Measuring and Instrumentation | 4,65 |
| Software Design | 3,98 |
| Activation of Electric Systems | 3,81 |
| Modelling and Simulation of the Physical World | 3,69 |
| Co-Design of Apps | 3,01 |
| Grand Challenges of Engineering | 2,82 |
| Design Nature | 1,68 |
| **Course Units - LASSI** | |
| **Course Units** | **NS** |
| Grand Challenges of Engineering | 1,73 |
| Modelling and Simulation of the Physical World | 1,14 |
| Software Design | 1,03 |
| Measuring and Instrumentation | 0,88 |
| Physics of Movement | 0,62 |
| Design Nature | 0,56 |
| Mathematics of Variation | 0,53 |
| Data Science | 0,43 |
| Activation of Electric Systems | 0,00 |
| Co-Design of Apps | -0,99 |

The second subdivision shows Node Strengths between course units, with the prevalence of STEM related ones. The third subdivision shows aspects of the LASSI that have the strongest connections with course units, which highlights Concentration as the most central node. The fourth subdivision shows node strengths of course units with LASSI aspects, with low values of centrality.

# 6 Conclusion

Our results show that there is a measurable correlation of Concentration with most course units related with STEM, or quantitative aspects. Also, Concentration relates to a small subcluster of aspects of Autonomy for Learning which can be compared with Resilience and to Conscientiousness, previously identified with academic performance in the works of O'Connor & Paunonen (2007).

As side results, we discovered that the correlations between aspects of the LASSI are not strong, what substantiate that those ten aspects are independent components of the Autonomy for Learning (Weinstein, Palmer, Acee, 2016), and strong correlations of course units that are quantitative driven.

Results suggest that researchers on Engineering Education should concentrate on developing Concentration of students as an important predictor of academic success, as measured by final grades in course units. We quote from the LASSI Manual (Weinstein, Palmer, Acee, 2016): "Concentration helps students to focus their attention on school-related activities, such as studying and listening in class, rather than on distracting thoughts, emotions, feelings, or situations. … Learning techniques for focusing attention and maintaining concentration help students implement effective learning strategies and can make learning and studying both more effective and more efficient."

Further work may include following the same students on their third semester of academic progress, studying students for other courses, such as Business and Administration, Economics, Law, and Computer Science and comparing with the results of Engineering Students. Another line of work is investigating how aspects of the Autonomy for Learning, such as Concentration, may be developed in college students, and test if an increase in this aspect leads to better academic results.

Since correlation does not imply causation, we also plan to address the issue of causality, an aspect that cannot be measured by correlation alone, to check if there could be other factors not considered that help explain our findings. Transfer Entropy, that is derived from Shannon Entropy from Information Theory, will be used as a tool.

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# Formative Assessment in Engineering Courses at PUJ: Faculty Perspectives on Assessment.

Alejandra M. González[1], María P León[2], Hermes A. Vacca[2]

[1] Ucollege Javeriana, Academic Vice President's Office, Pontificia Universidad Javeriana, Colombia
[2] Civil Engineering Department, School of Engineering, Pontificia Universidad Javeriana, Colombia

Email: agonzalez@javeriana.edu.co, mpleon@javeriana.edu.co, vacca@javeriana.edu.co

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**Abstract**

The role of assessment is pivotal in the teaching-learning process, serving as a guiding tool for students to understand the necessary improvements to achieve competency. While summative assessment remains prevalent in teacher-centered learning approaches, a shift towards curriculum reform, such as the CDIO initiative at the School of Engineering, Pontificia Universidad Javeriana, is fostering a transition towards more active, student-centered pedagogical practices. Given the fundamental nature of evaluation in teaching, this study integrates data from surveys and interviews to explore faculty evaluative practices and their conceptualizations of assessment. Key factors essential for effective feedback and transparency within the assessment framework, including the communication of learning outcomes and assessment criteria, undergo thorough examination. Findings reveal that approximately half of the faculty members prioritize encouraging students' critical reflection on their learning processes, aligning with their feedback strategies. However, some faculty still lean towards grading of student knowledge. This study lays the groundwork for continued discussion on assessment processes within the School of Engineering

**Keywords**: Active Learning; Engineering Education; Assessment; Feedback, Faculty.

## 1 Introduction

The need to train professionals with the skills for the 21st century has driven the transformation of teaching practices in engineering education. Gradually, changes have been made from teacher-centered teaching to student-centered teaching. In this kind of teaching, meaning is achieved by students when they actively select and cumulatively construct their knowledge through individual and social activities (Biggs, 2001). The changes in the focus of student-centered teaching lead to the alignment of the elements that are part of teaching and that not only concern the teacher-student relationship but also the types of tasks, infrastructure, pedagogical practices, and evaluation systems Kolmos (2004). According to Biggs (2001), the optimization of the educational process is achieved when learning objectives, pedagogical strategies, and evaluations are coherently integrated. Formative assessment particularly proposes a tool as that allows continuous and meaningful feedback on learning progress. Assessment allows both teachers and students to obtain information from the evaluation process and act either to improve the learning process or so that the student can demonstrate their progress in achieving the result (Black and Wiliam, 2018). Formative assessment facilitates the development of metacognitive and self-regulatory skills, allowing students to identify their strengths and areas for improvement (Black and Wiliam, 1998). The transition of teachers from a culture of summative assessment to formative assessment remains challenging, despite the development of skills that allow the student to learn to learn (Lopez-Caudana et al., 2020), necessary for the development of 21st-century skills.

Effective feedback practice includes clarity of assessment criteria, timeliness of feedback, and encouraging student reflection on their own learning. Nicol, D. J., and Macfarlane-Dick, D., (2006) propose a model of effective feedback practice that indicates the seven principles that should be included: helps clarify what good performance is, facilitates the development of self-assessment (reflection) in learning; delivers high-quality information to students about their learning; encourages teacher and peer dialogue around learning; encourages positive motivational beliefs and self-esteem; provides opportunities to close the gap between current and desired performance; finally, Provides information to teachers that can be used to help shape teaching.

The above described has important implications for teaching practice and assessment design. Sambell et al. (2013) highlight the relevance of the design of evaluation tasks as a fundamental element to be able to provide effective feedback. The evaluation tasks provide important information regarding the educational approach based on the answers that come from two questions: why evaluate? and what to evaluate. (Ibarra-Sáiz, M.S., 2023). The responses may demonstrate three evaluative approaches: learning evaluation, which seeks to report on the student's competence about learning outcomes; assessment as learning, which allows teachers to determine the next steps to advance student learning; and evaluation as learning that guides and provides opportunities for each student to monitor and critically reflect on their learning and identify the next steps to follow.

Guaranteeing the quality of teaching is based on the orientation proposed by Biggs, which in practice has led universities to adopt educational models with constructivist frameworks of reference. Particularly at the Pontificia Universidad Javeriana, the CDIO (Concieve-Design-Implement-Operate) model was adopted for the reform of engineering programs. Implementing this model requires that faculty be equipped with the understanding of how to implement changes and be provided with relevant guidance and resources (Crawley, et al., 2014). After three years of implementation of the CDIO model in the Faculty of Engineering of the Pontificia Universidad Javeriana (PUJ), it is relevant to understand how the proposed educational models affect the practices of teachers, and particularly evaluation processes.

## 2 Methodology

The research question was answered through a qualitative exploratory methodology. The research aimed to understand the nature of evaluations conducted by the faculty of the Faculty of Engineering of the PUJ. The data was collected through a survey, and responses were analyzed through categorization to identify emerging patterns. The questionnaire was based on Ibarra-Saíz's research and included open-ended questions to triangulate the information and draw conclusive insights about evaluative practices of the professors. Three types of questions were asked: The first group of questions sought to understand the evaluative intention, such as what is being evaluated and what it's being evaluated for. The answers were presented in a predefined manner according to the conceptualization given by Ibarra-Saínz. Respondents were asked to organize the relevance of these questions according to their conceptions of evaluation. The second group of questions was extracted from the scale presented by Ibarra-Saínz to measure the perceptions of university professors regarding evaluative procedures. Table 1 presents the questions asked, and respondents were asked to answer with a frequency scale ranging from always to never.

A final group of questions corresponded to those that provided detailed information about the teacher's practice. The following open-ended questions were asked: What is feedback for you? How do you give feedback? What do you consider to be the essential factors for good feedback?

Table 1. Questions for understanding evaluative practice.

| Questions |
| --- |
| Do you give feedback? |
| Do you give feedback on non-evaluative work? |
| Do you give feedback on an evaluative work? |
| Learning outcomes, criteria, assessment procedures and grading system of the course are public |
| The evaluation system informs about what students must deliver or execute |
| The evaluation system informed about the evaluation criteria and instruments |
| The evaluation system informs of the four modalities (self-evaluation, peer evaluation, shared evaluation, evaluation by the teacher). |
| Assessment tasks, students must perform, are informed and described |
| Assessment tasks involve the student's use of relevant knowledge and content of the course |
| Assessment tasks are presented as a challenge for the student |
| Assessment tasks facilitate the application of knowledge and skills to real-life situations or cases |
| Feedback is provided to students on their progress during the teaching-learning process |
| It makes it easier for students to participate and provide self-feedback by contrasting their progress with the assessment instruments provided to them previously |
| Students receive feedback on their progress from their peers through peer review |
| It makes it easier for students to collaborate in defining some elements of the assessment system |
| Students self-evaluate their products or performances, either individually or in groups |
| Evaluation and graded is taken place in a dialogic way (between teachers and students) and by consensus |

Regarding the data analysis tools used in the survey, a simple trend analysis was conducted on each question to identify general patterns. Subsequently, mosaic plots were employed, which are graphical representations of two-way contingency tables, to visualize the relationship between two or more qualitative variables. Additionally, a Sieve Diagram, a graphical method for visualizing frequencies in a two-way contingency table and comparing them to expected frequencies under the assumption of independence, was utilized. This technique allowed for a deeper evaluation of the associations between the variables under study. Following this, an analysis of open-ended questions was performed, where the most recurrent themes for each question were identified, the most representative words from the responses were extracted, and their relationship with the themes was explored using the Dirichlet algorithm. Finally, a sentiment analysis was conducted to detect polarities in the responses and possible correlations among them. This approach provided a more comprehensive understanding of the attitudes and emotions expressed by the respondents, aiding in identifying underlying patterns and significant trends in the collected data. The combination of these techniques allowed us to identify correlations, coherence, and inconsistencies in the responses, as well as to determine with the responses to other survey questions what could be the origin of such inconsistencies.

## 3 Results and Analysis

The survey revealed a diverse distribution among the surveyed professors. Of the total respondents, 14 professors belong to or teach in the field of electronic engineering, 12 in civil engineering, and 2 in industrial engineering. Among these, 16 are full time professors and 12 are partial time professors. Regarding the distribution by semester, it is observed that most professors teach in the seventh or eighth semester, with a significant number also in the first and second semesters. A trend analysis regarding the question about evaluation criteria identified five main categories: progress, measurement, thinking, and combinations of these priorities. Most professors prioritize measurement and progress, followed by thinking. In terms of evaluation objectives, three main aspects were identified: certifying student competence, guiding their learning, and providing information to faculty. Most professors consider evaluation primarily serves to guide student learning, followed by certifying their competence and providing information to faculty.

It is relevant to note that most respondents have experience teaching in multiple semesters, suggesting a wide range of pedagogical skills and a deep understanding of the learning process throughout students' academic careers. This variety in teaching experience may influence the perception and application of evaluation criteria, as well as how evaluation results are used to inform and improve teaching. Professors with more experience at different levels of the curriculum may have a more holistic view of student needs and thus adapt their evaluation methods and feedback more effectively. Regarding feedback provided to students, there is a clear preference for providing feedback consistently. Most professors claim to offer feedback always or most of the time, while only a few indicate that they occasionally provide this type of feedback. This trend is more pronounced among full time professors, who tend to offer feedback more consistently compared to partial time professors.

Identifying relationships between questions using mosaics suggests a connection between the perception of the evaluation purpose and how evaluation is conducted. Professors who consider evaluation primarily as a measure of student performance tend to evaluate and grade more dialogically, possibly to gain a more comprehensive understanding of the level of competence achieved. On the other hand, professors who view evaluation as a tool to guide the learning process, although they may also evaluate dialogically, tend to do so occasionally, suggesting a more balanced approach between direct feedback and other evaluation methods. The contrast of responses in the mosaics shows a difference in evaluation practices between full time and partial time professors. Full time professors tend to provide feedback on non-evaluative assignments more consistently, which could be related to their greater dedication time at the university. On the other hand, partial time professors tend to provide this feedback occasionally, which could reflect less availability of time due to other responsibilities off-campus. The mosaics suggest that the perception of the evaluation object influences how evaluation is conducted. Professors who see the evaluation object as student progress tend to evaluate non-dialogically most of the time. This may indicate that these professors prioritize observing student progress over time rather than direct interaction during evaluation.

The analysis shows significant correlations in the relationship between feedback offered by professors and the clarity in evaluation criteria and procedures: There is a strong correlation observed between professors who consistently provide feedback and those who consistently make evaluation criteria public. This indicates a consistent transparency and clarity in the expectations set by these professors. Moreover, professors who offer feedback consistently are also those who articulate and elaborate evaluation tasks with precision and clarity. This underscores their commitment to providing clear guidance to students regarding their evaluation expectations. Furthermore, a correlation emerges between professors who consistently provide feedback and those who assign challenging evaluation tasks to students. This suggests an intentional effort on the part of these professors to foster student growth and development through substantial task challenges. Additionally, the data reveal that professors who consistently offer feedback are inclined to promote the application of knowledge and skills to real-life scenarios in evaluation tasks. This signifies an integrated approach to evaluation, aimed at equipping students with the ability to apply their learning in practical contexts. In summary, the results of the analysis show a close relationship between teachers' feedback practices and transparency in evaluation criteria and procedures. This underscores the importance of clear and consistent communication in the evaluation process to support effective student learning.

The analysis of responses to open questions about feedback reveals several important topics and consistent patterns. We present these topics and some examples of the original responses from the teachers:

- Interaction between teachers and students: Most teachers perceive feedback as an interaction between them and their students in a specific space, allowing them to address elements of the learning process. "A space for interaction between the teacher and their students, where the teacher addresses the assessments conducted with the students.
- Awareness of errors and critical process: Feedback is perceived as a process that allows students to become aware of their mistakes, resolve them, and improve, which is considered fundamental for academic progress. "Solving an exam or an assignment so that the student becomes aware of their mistakes."
- Identification of skills and performance: The importance of feedback in identifying students' skills and performance is highlighted, as well as in communicating their weaknesses and improvement opportunities. "Establishing a bilateral academic dialogue by critical thinking, and reflection - including self-reflection- on the respective academic activities and learning content. It aims to promote student autonomy in learning, appreciation of achievements, improvement of learning methods and processes, and enhancement of professional competencies."
- Relationship with evaluation: Feedback is closely related to the evaluation process, as it allows for identifying shortcomings, learnings, and outcomes, as well as offering improvement opportunities. "Feedback is taking the result of the evaluation, highlighting positive aspects and areas for improvement so that the student can then complement their learning."
- Reflection and development of strengths: The importance of feedback in fostering reflection and the development of students' strengths is mentioned, as well as in identifying areas for improvement and growth opportunities. "It refers to the process of identifying the strengths and weaknesses of the student to provide feedback or information about their performance, with the purpose of enhancing and adjusting their professional progress. "
- Classroom environment as preferred space: Most teachers consider the classroom environment as the preferred space for providing feedback, although other means such as written evaluations or email are also mentioned. "I provide constructive criticism in class, personally, and in a way that the student feels confident with me."
- Emphasis on the evaluation process: Evaluation is highlighted as a key element in the feedback process, as it provides relevant information to improve learning and student performance. "An integral part of the evaluation process, as it involves not only grading but also improvement."
- Respect and mentoring attitude: The importance of maintaining a respectful environment and a mentoring attitude when providing feedback is emphasized, as well as offering constructive and quality feedback. "Transparency, acceptance, truth, and respect are key factors."

To sum up, teachers view feedback as a fundamental process enabling students to reflect on their learning, identify areas for improvement, and enhance their skills. They emphasize the intimate connection between feedback and the evaluation process, along with the significance of fostering a respectful and collaborative classroom environment. Thus, to the question, "What is feedback for you?", several categories can be identified: Teacher-Student Interaction, where feedback serves as an interaction to address aspects of the learning process; Awareness of Mistakes, as feedback helps students recognize and rectify errors; Identification of Skills and Performance, with feedback playing a vital role in identifying skills and communicating performance; Relationship with Evaluation, as feedback is closely related to the evaluation process to identify weaknesses and lessons learned; and Reflection and Development of Strengths, where feedback is seen as a process that encourages reflection and the development of strengths.

However, when asked about "How do you provide feedback?", it appears that the process is primarily focused on identifying and collecting evaluation evidence. The identified categories include: In-Class Feedback, where the classroom serves as the primary setting for feedback delivery, encompassing written assignments, exams, and group discussions; Socialization of Results, highlighting the importance of sharing evaluation outcomes to grasp their impact on learning; Identification of Errors and Opportunities, viewing feedback as a means to recognize errors and areas for improvement; and Personalization and Adjustment to Rubrics, emphasizing the personalized delivery of feedback tailored to established rubrics. In response to the question, "What are the essential factors for good feedback?", the following categories were identified, aligning with those from previous open questions: Encouragement of Reflection, emphasizing the importance of fostering reflection as a crucial factor for effective feedback; Identification of Skills and Performance, underscoring the significance of recognizing student skills and performance levels; Relationship with Evaluation, highlighting evaluation as a pivotal aspect of good feedback; and Respect and Mentoring Attitude, stressing the importance of maintaining respect and adopting a mentoring approach when delivering feedback.

The result of the sentiment analysis of the open questions generates two poles of analysis, the first focused on the identification of errors and constructive criticism and the second focused on reflection, learning, and continuous improvement. In summary, teachers value feedback as a process of interaction and reflection primarily carried out in the classroom, and consider the relationship with the evaluation process, the encouragement of reflection, and mutual respect essential for effective feedback.

# 4 Conclusions

There is a significant coherence between evaluation criteria and evaluation objectives. Most teachers prioritize measuring student progress and use evaluation as a tool to guide and improve the learning process. However, their practice focuses on identifying competence levels, but the process of constructive feedback, which teachers themselves value as an essential activity in the learning process, is not evident. Although teachers recognize the importance of feedback in identifying errors and areas for improvement, some seem to focus more on evaluating performance than on the learning process itself.

This could create a discrepancy between the stated intention of feedback and its practical application. The widespread position of teachers is to emphasize the importance of providing feedback to students, both in evaluative and non-evaluative assignments, reflecting significant commitment from teachers to support student learning. However, it is important to consider the diversity of experiences and pedagogical approaches within the faculty when designing evaluation policies and practices, with the aim of ensuring that the individual needs of students are addressed and promoting an inclusive and effective learning environment. Teachers recognize feedback as a fundamental component of the teaching-learning process, allowing students to become aware of their mistakes, identify skills, and improve their performance.

Most teachers consider feedback to be intrinsically linked to performance evaluation and the identification of shortcomings and learnings. At this point, the role of feedback in fostering reflection and the development of strengths is highlighted, beyond simply identifying errors. Teachers emphasize the importance of creating a learning environment that promotes self-reflection and personal growth of students. Although most teachers mention the importance of written feedback and in-class discussion, some topics suggest that the practical application of feedback may be inconsistent. For example, mentioning written feedback but then focusing on socialization in class could create confusion about the optimal way to provide feedback. The above findings highlight the importance of continuous reflection on teaching practices and assessment of learning, as well as the need for greater clarity and coherence in the implementation of feedback strategies in the classroom. These findings can be attributed to several factors:

- Individual Perception: Each teacher may have a different understanding of what constitutes effective feedback and how it should be applied. This perception may be influenced by their training, previous experience, and teaching style.
- Institutional Focus: Institutional policies and practices can influence how teachers understand and apply feedback. If the institution emphasizes evaluation more than the learning process, teachers are likely to reflect this approach in their responses.
- Lack of Conceptual Clarity: Feedback is a broad concept that can encompass different approaches and practices. The lack of a clear and agreed understanding of what constitutes effective feedback can lead to divergent interpretations and, therefore, inconsistency in its application.
- Time and Resource Constraints: Teachers may face time and resource constraints that affect their ability to provide feedback consistently and comprehensively. This may result in prioritizing certain aspects of feedback over others, contributing to discrepancies in responses.
- Training and Professional Development: Initial and ongoing training of teachers around feedback may vary, affecting their understanding and application of best practices in this area. The lack of professional development opportunities focused on feedback may also contribute to these inconsistencies.

In a second stage of the study with teachers, key aspects related to the feedback process in the educational field will be further explored. Fundamental questions will be raised, such as: How could the feedback process be improved to ensure greater student participation and engagement? and What strategies could be implemented for students to more effectively utilize the feedback received to enhance their learning? Additionally, the barriers and challenges faced by teachers in consistently providing quality feedback will be explored, as well as the impact of students' perceptions and expectations on the effectiveness of this process. Furthermore, the impact of formative feedback on academic performance and student motivation will be investigated.

Concurrently, several future works are projected to expand knowledge in this field. It is proposed to investigate the impact of different approaches and techniques of feedback on academic performance and student self-efficacy. Additionally, the implementation of educational technologies to improve feedback and progress monitoring of students will be explored. Finally, longitudinal studies will be conducted to assess how feedback received during the formative process affects professional development and employability of graduates. These investigations aim to significantly contribute to the continuous improvement of the feedback process in the educational environment.

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# Professor's Experiences in Reflective Portfolio for Materials Engineering Program

Esoly Madeleine Bento Dos Santos[1], Denise Hirayama[1]

[1] Fluminense Federal University, Volta Redonda-RJ, Brazil

Email: denisehirayama@id.uff.br

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**Abstract**

In Brazil, on April 24, 2019, the Ministry of Education issued Resolution CNE/CES No. 2, unveiling major revision National Curricular Guidelines for undergraduate Engineering Programs. These revisions aim to modernize course curricula and enhance the preparation of future engineers, with a focus on essential skills and competencies. In fields like Health Sciences Education, teachers have utilized Reflective Portfolios to showcase achievements alongside personal and professional development. This is accomplished through critical reflection on evidence derived from their experiences. This paper aims to analyze and discuss the implementation experiences of both teachers and students regarding Reflective Portfolios, while also exploring their impact on student learning. Spanning 15 weeks during the second semester of 2023, the study was conducted with students at Fluminense Federal University registered in the Thermoplastic Processing of Material Engineering Program. The students were tasked with submitting reflective portfolios, discussing the learning acquired during the course, to a fictional company, which could use this document in the selection process. The development of skills and competencies acquired through the implementation of reflective portfolios was assessed using quantitative methods such as the Friedman test, along with qualitative analysis of open-ended responses. Findings suggest that students perceived themselves as highly proficient in their skills and competencies; however, according to the quantitative study, no significant differences were discerned in their performance or grades throughout the course duration. The study concludes that, although significant advancements in skills and competencies may not be perceived within the study period, their value lies in cultivating self-awareness and facilitating experiential learning. Despite the need for further investigation, the study advocates for the ongoing utilization of reflective practices in engineering education to nurture holistic student development.

**Keywords**: Reflective Portfolio; Material Engineering; Skills; Competencies; Engineering Education.

# 1 Introduction

In Brazil, on April 24, 2019, the Ministry of Education issued Resolution CNE/CES No. 2, unveiling major revision National Curricular Guidelines for undergraduate Engineering Programs (Brasil, 2019). These revisions, along with Resolution CNE/CES No. 1/2021, aim to reform course curricula and enhance the preparation of future engineers, with a focus on essential skills and competencies (Brasil, 2021). Considering the significance of skills and competencies for engineering students, providing opportunities for reflective practices is essential, as they serve to promote the development of students in these areas.

Given 'reflection' denotes the cognitive process enabling the conversion of experience into personal knowledge by bridging emotional and cognitive states, the incorporation of reflective practice should mirror the student's individual contemplation regarding the efficacy of their learning. The reflective portfolio serves as a tool for reflective practice, enabling teachers and students to develop a comprehensive understanding and facilitating a more efficient assessment of their learners' knowledge and skills (Efe, 2016).

Reflective portfolios are collections of evidence that, through critical reflection, highlight achievements alongside personal and professional growth. They usually contain written evidence detailing both learning outcomes and processes. By providing a critical analysis of their contents, portfolios serve as tangible evidence of achievement and personal/professional development (Plaza, Slack, Skrepnek & Sauer, 2007). Reflection is a fundamental aspect of a portfolio, along with the student-teacher relationship and clear guidelines for portfolio construction (McMullan, 2003).

The students demonstrate ongoing acquisition of skills, knowledge, attitudes, understanding, and achievements, rendering it a dynamic record of growth and professional evolution. Reflective Portfolios encompasses both retrospective and prospective elements, reflecting the current stage of individual development and activity. Moreover, it effectively communicates the qualities, competencies, and abilities of the owner, while also indicating potential areas for development. Another advantage of implementing Portfolios in the course is the reinforcement of learning. The reflective component can provide this link between theory and real professional practice, thereby helping to reduce the 'reality shock' experienced by many students when they transition into practice (McMullan, 2003).

In fields such as Health Sciences Education, educators have embraced Reflective Portfolios as a means to showcase their achievements and foster personal and professional development. This process involves critical reflection on evidence drawn from their experiences, facilitating insights, practice refinement, and ongoing development, often within the context of patient care (Plaza., 2007; Cordeiro & Silva, 2020). In the realm of engineering, this approach has been integrated with project-based work, contributing to enhanced graduate abilities in articulating thoughts and sharing experiences with peers, professionals, and the public (Helwig, Simmons, & Goh, 2019). Carroll and colleagues' approach (2007) involved to transferable skills through both individual and collaborative reflective learning, all facilitated by open-source software developed by the team (Carroll, Markauskaite, & Calvo, 2007).

In higher education in engineering, one widely used tool is the Electronic Portfolio (e-portfolio), which are a web-based information management system that utilizes electronic media and services. This system offers a dynamic, flexible, and interactive way to document academic and professional progress. In this context, it is essential to have platforms that host these portfolios, such as Mahara, PebblePad, and Foliotek. E-portfolios can also be utilized to maintain transparent records for learning pathways, credit transfers, and various modes of participation and assessment (Alam, Chowdhury, Kootsookos & Hadgraft, 2015). In Brazil, the study of e-portfolios as a pedagogical tool within the engineering curriculum, particularly in Engineering in Industrial Design and Product Development, demonstrated that these new teaching and learning models in higher education institutions could be implemented to facilitate the teaching of technical subjects through the English language. (Polyakova, Juliá-Sanchis, Galstyan-Sargsyan & Galstyan-Sargsyan, 2023)

Initial testing of portfolios with engineering students is important to ensure the successful implementation of this methodology in any educational program. After the method proves successful, incorporating technology into portfolios can significantly enhance learning outcomes. This paper aims to analyze and discuss the experiences of both teachers and students using Reflective Portfolios. It will also explore the impact of these portfolios on student learning, skill development, and competency acquisition within the materials engineering student body at Fluminense Federal University, Brazil. Through this analysis, the study seeks to provide insights and recommendations for the broader application and integration of Reflective Portfolios in engineering education.

The Materials Engineering program at the Federal Fluminense University (UFF) is based in the interior of Rio de Janeiro state, specifically at the School of Industrial Metallurgical Engineering of Volta Redonda (EEIMVR). Commencing in the second semester of 2018, the Materials Engineering course admitted 20 students per semester, culminating in its inaugural graduating class in 2023. In the same year, the curriculum underwent revision with the introduction of a new Pedagogical Project of the Course (PPC). This initiative aimed to update the competencies and skills required by students, fostering the development of engineers capable of addressing contemporary societal and industrial challenges with creativity and responsibility, while considering human, social, technical, and ethical dimensions (Universidade Federal Fluminense, 2018).

The professional disciplines within the program are structured into four knowledge tracks: Materials Science and Engineering, Metallic Materials, Ceramic Materials, and Polymeric Materials. Reflective portfolios were introduced for third-year Material Engineering students, particularly within the Polymeric Material track, focusing on Thermoplastic Processing. This course aimed to equip students with an understanding of fundamental thermoplastic polymer processing techniques, enabling them to determine material types, processing methods, and suitable operational conditions for specific product production.

# 2 Methodology

## 2.1 Procedure

The students were encouraged to create their portfolios based on a proposal for a fictional company, as described below:

*"You are participating in the selection process for the position of Engineer at a renowned company specialising in the commercialization of thermoplastic processing equipment. In the final stage of the selection process, the company provided a comprehensive course on Thermoplastic Processing, through which candidates will be evaluated via a reflective portfolio."*

Subsequently, the students received a tutorial on how to construct the Reflective Portfolio and followed the instructions outlined below:"

1. It was recommended to use a presentation program.
2. The Portfolio should begin with a self-description, addressing questions such as: Who am I? Where do I come from? How do I intend to contribute to the company?
3. The essential concepts related to the theme were to be included in the Portfolios, used texts, images, audio, video, links, or paper.
4. Finally, students were required to reflect on what they had learned. This section of the Portfolio should address questions such as: What have I learned from this activity? What challenges did I encounter and how did I overcome them? How has this experience contributed to my personal and academic development? How can I apply what I have learned in the future?

To ensure the quality of the portfolios, students are given the opportunity to review their work and make any necessary corrections before evaluation.

## 2.2 Evaluation

The Reflective Portfolios were evaluated throughout the semester by both professors and students based on the following criteria: Knowledge, Reflection, Creativity, Layout, and Essay. These criteria are scored on a scale from 0 to 100, with ratings of Excellent, Good, Average, and Poor.he portfolio grade was determined as an average of the assessments provided by the teacher and the student. However, in cases where the disparity between the grades exceeded 30%, the student's grade was adjusted to align closely with the teacher's assessment.

The self-assessment of skills and competencies for students is conducted on a scale from 10 to 0, encompassing the following dimensions: Analysis and Problem Solving, Oral and Written Communication, Technical Knowledge, Socio-environmental Awareness, Creativity, Results Interpretation, Leadership, Strategic Planning, Punctuality and Attendance, Proactivity, Decision Making, and Teamwork. The students can provide suggestions and comments regarding the strengths and weaknesses of their skills and competencies through open-ended responses.

### 2.3 Data Analysis

To describe the distribution and variability of portfolio grades data, various statistical measures were computed, including the average, median, and standard deviation to evaluate the performance of ten students. The data were collected in the second semester of 2023 during the Thermoplastic Processing course in the undergraduate Materials Engineering program.

The development of skills and competencies acquired through the implementation of reflective portfolios was assessed using non-parametric analysis, such as the Friedman test. This test was employed to ascertain any variations or distinctions among research variables across thematic progressions. Specifically, the statistical theory under examination is outlined as follows:

- Null Hypothesis (H0): The mean ranks of variables are equal, indicating no difference in performance among students' self-assessment of their skills and competencies across thematic progressions.

- Alternative Hypothesis (H1): The mean ranks differ significantly, indicating differences in performance among students' self-assessment of their skills and competencies across thematic progressions.

The significance level for this hypothesis testing is set at $\alpha = 0.05$. H0 is rejected if $p < \alpha$. These non-parametric analyses were conducted using jamovi software version 1.6.23 under a free license (https://www.jamovi.org).

Furthermore, qualitative analysis was conducted on open-ended responses. The question posed was: "Identify a competency or skill that stood out in the development of this section of the Portfolio and provide justification for its assessment rating.

## 3 Results and discussion

***Portfolio Assessment***

According to the professor, the significant challenges encountered during portfolio implementation included the absence of reflective components in student activities, students failing to submit the complete portfolio, and discrepancies between the assessments of the professor and the students. These challenges manifested in fluctuations in the average grades across the semester's themes, as depicted in Table 1.

Table 1. Grade of course along of semester.

| | Themes covered during the Thermoplastic Processing course | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Polymer** | **Rheology** | **Processing** | **Extrusion** | **Injection Molding** | **Other Processing** | **Additives** | **Blends** |
| Average | 77.8 | 70.8 | 72.0 | 65.5 | 57.5 | 61.3 | 60.8 | 70.3 |
| Median | 79.0 | 70.5 | 72.0 | 69.5 | 68.0 | 61.5 | 65.0 | 66.5 |
| Standard deviation | 5.0 | 5.3 | 0.8 | 15.5 | 28.9 | 18.9 | 19.8 | 12.6 |
| Minimum | 71.0 | 65.0 | 71.0 | 44.0 | 15.0 | 38.0 | 33.0 | 60.0 |
| Maximum | 82.0 | 77.0 | 73.0 | 79.0 | 79.0 | 84.0 | 80.0 | 88.0 |

Although the majority of average grades for the themes exceeded 60 points (the minimum grade requirement for passing the course), the overall average was not as high, due to lower scores in the reflection item and lack of creativity in the Portfolios. While the maximum grade improved in the last themes compared to the first, the worsening of the minimum suggests that while the top-performing students have made strides, many students still find it hard to achieve the learning goals.

In the case of the Injection Molding and Additives, the data distribution is asymmetric, as indicated by the significant difference between the average and median. This result, along with the minimum value of 15, suggests that some students with lower scores are pulling the average down.

The lower scores of these students were attributed to deficiencies in reflection, creativity, and the absence of certain items in their portfolio submissions. Regarding reflection, the lower scores were mainly due to two factors: firstly, students rarely engaged in reflective practices during the engineering course; secondly, they lacked self-awareness. Despite receiving training on portfolios and feedback from the professor, students found it challenging to incorporate meaningful reflection into their work. As for creativity, it demands dedication and time to innovate, which resulted in grade variations based on this criterion. Consequently, some students couldn't allocate enough time to their portfolios due to commitments to other courses throughout the semester, leading to the absence of some items in their portfolio submissions.

***Self-assessment of skills and competencies***

Figure 1 illustrates the average perceptions of students regarding their performance in technical knowledge and creativity. These self-assessment serves as a tool to exemplify students' perceptions of their skills and competencies during the implementation of themes in course of Thermoplastic Processing.

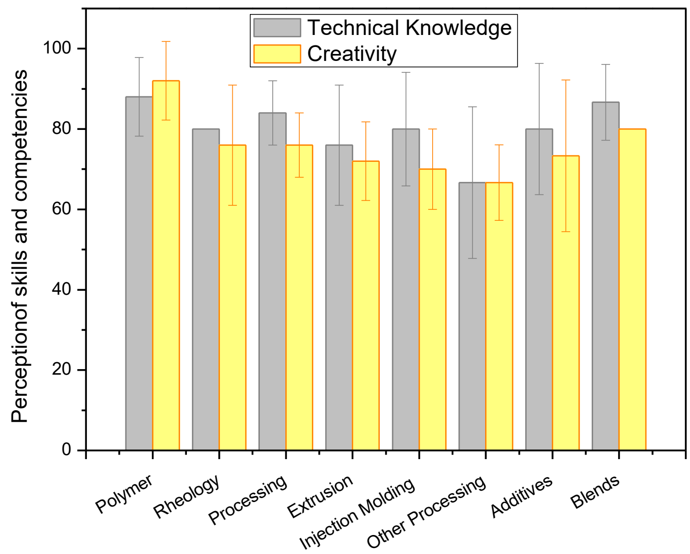


Figure 1. Students' perceptions of their skills and competencies

The results of Figure 1 revealed that students perceive these skills (technical knowledge and Creativity) to be highly proficient, with performance scores exceeding 70. However, the thematic progression in the course did not seem to reflect such advancements in their expertise. In essence, they did not detect any enhancement in these skills as they already assessed them to be above the anticipated level. To validate potential significant differences in students' self-assessment of their skills and competencies throughout the semester, the Friedman test was employed. Table 2 show the results of the Friedman test concerning the skills and competencies identified by students within their portfolios.

Table 2. Result of Friedman Test.

| Skill and competence | p-value |
|---|---|
| Oral and Written Communication | 0.309 |
| Technical Knowledge | 0.154 |
| Creativity | 0.075 |
| Results Interpretation | 0.113 |
| Strategic Planning | 0.035 |
| Punctuality and Attendance | 0.128 |
| Proactivity | 0.083 |
| Decision Making | 0.080 |

The skills and competencies, such as Analysis and Problem Solving, Socio-environmental Awareness, Leadership, and Teamwork, are absent from this table because students considered that these skills and competencies were not involved in the construction of portfolios.

All evaluated skills and competencies show values higher than 0.05, indicating no significant difference in performance among students' self-assessment of their skills and competencies across thematic progressions. Consequently, the skills and competencies at the end of the course were considered equal to those at the beginning of the course, as assessed by the students.

According to literature the students have difficult to mark realist grade when they do self-assessment. Browna and Harrisb's (2014) research sheds doubt on the efficacy of self-assessment as an evaluation method, emphasizing the importance of certain conditions for students' judgments to be deemed useful, valid, and reliable. And the Chur-Hansen (2001), said that the students' uncertainty about their ability to grade because mainly the difficult to be objective and no experience in grading/uncertain about standards. Then, the professors of this research presented another set of questions to the students, this time focusing on open-ended inquiries about competencies and skills. These open-ended questions revealed some general insights presented in Table 3.

The students recognize the need to enhance their skills to diverge from the conventional. The improvement by applied Reflection Portfolio is exemplified by the Selected Raw Data of Creativity, where students evaluated their skills in the themes "Polymer" (the initial theme) and "Additives" (nearly the final one). It is evident that they recognize their progress in their work, which is also apparent in their perception of Technical Knowledge and Reflection. However, they also acknowledge the potential for further refinement in these skills.

Despite the Friedman test indicating that students did not improve these skills or competencies, the open-ended questions revealed that students acknowledged improvement in these areas. They were capable of evaluating their progress and demonstrated responsibility for their advancement. This phenomenon is known as self-regulation. The utilization of self-assessment within assessment for learning policies relies on theories of self-regulated learning, which recognize that students can improve their self-regulation skills through self-assessment, students set targets and evaluate progress against criteria, thereby enhancing their accountability for tracking their progress (Brown, Gavin & Lois Harris, 2014).

Table 3. Responses from students to open-ended questions regarding competencies and skills

| Skills and competences | Theme | Selected raw data |
|---|---|---|
| Creativity | Polymer | *"I believe it is necessary to express my creativity in other ways so that the portfolio stands out compared to more conventional presentations."* |
| | Additives | *"A very creative portfolio, however, I believe it should include more technical knowledge to better delve into the subject."* |
| Technical Knowledge | Rheology | *"The technical knowledge required to interpret the behavior described in the graphs relating to the samples."* |
| | Extrusion | *"Technical knowledge - It was one of the deliveries with the most detailed information."* |
| Reflection | Polymer | *"I was able to explain the topics well, but I had difficulty with reflection."* |
| | Extrusion | *"From the extrusion portfolio, I did all the reflections, which had been a challenge until then. I believe this is a positive point."* |

This study of reflective portfolios for the Materials Engineering Program presented several limitations, such as a small group of students involved, a large volume of portfolio submissions that hindered quick feedback for the students, the significant time investment required from both professors and students, and the students' lack of maturity in conducting self-assessment. Based on this experience, future projects will involve planning to reduce the number of portfolio submissions, providing guidance on self-assessment, and expanding the implementation of reflective portfolios to more courses within the Materials Engineering program. Additionally, future research should compare the effectiveness of reflective portfolios with traditional assessment methods in terms of promoting student learning and competency development. It should also investigate how the use of reflective portfolios can contribute to preparing students for the job market in the field of Materials Engineering, and how the implementation of platforms for e-portfolio usage can help facilitate teaching

# 4 Conclusion

The results of Reflective Portfolios for students in the Thermoplastic Processing courses of the Materials Engineering Program at Fluminense Federal University indicate that although significant advancements in skills and competencies may not be perceived within the study period through Friedman Test, their value lies in cultivating self-awareness and self-regulation. Despite the need for further investigation, the study promotes the continuous use of reflective practices in engineering education to foster holistic student development.

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# Professors and Students Perception on the Implementation of Active Methodologies: A Case Study in the School of Industrial Metallurgical Engineering of Volta Redonda, Brazil

Emerson Carneiro Figueredo [1], Denise Hirayama[1], Tiago Brandão Costa[1], Ésoly M. Bento dos Santos [1]

[1] University Fluminense Federal, Volta Redonda, Brazil

Email: esolysantos@id.uff.br

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**Abstract**

This study aims to map pedagogical practices in the university context of the School of Industrial Metallurgical Engineering of Volta Redonda (EEIMVR), focusing on the principles of active teaching methodologies. The initiative arises amidst a context of the new National Curriculum Guidelines of 2019 and the growing use of Active Learning techniques, which are impacting other universities in Brazil and education in general. We opted for a survey research method, using electronic tools. Through two surveys, one to the faculty and another to the students, with similar questions, in order to compare both points of view on pedagogical practices, issues related to university teaching, and professor-student relationships. These questions were important for analyzing the perception of the use and implementation of active methodologies at EEIMVR. The research showed that professors have been applying the fundamentals of active learning in their classes and are open to updating themselves regarding these practices. Results also revealed that professors still do not have a formed opinion on relevant concepts of Active Learning, such as student-centered development and learning. It was also noticeable that, for professors, it is important to value the social side of the student in the pursuit of learning. A relevant difference was observed in some topics, such as dialogue. In the perception of the majority of students, professors are not open to course dialogue, a different situation from the faculty's perception, where the majority claim to be open to this type of conversation. Therefore, it was possible to map differences in the perceptions of the two groups and understand how this dynamic can be improved. In addition, some future actions were proposed that may contribute to the teaching-learning process and mitigate some perceived difficulties in the research.

**Keywords**: Engineering; Active Methodology; Active Learning; Higher Education.

## 1 Introduction

The last industrial revolution and globalization have driven scientific and technological advancements in the Brazilian job market, prompting the country to modernize its industrial sector to meet new standards. These advancements also impact higher education institutions, which now need to educate professionals prepared to deal with a market that demands skills such as creativity, leadership, and problem-solving (Furtado, 2013).

This scenario also motivated research by Brazilians such as Professor (Farias 2023), who mapped the profile of faculty members in the Electrical Engineering course at the Federal Institute of Pernambuco. According to his observations on career and faculty profile formation in Brazil, he noted the great need for pedagogical preparation for higher education professionals, who have the responsibility and mission of preparing students for the job market. This finding was corroborated by studies by (Paiva 2015), which, despite addressing a teaching scenario in vocational courses, remains relevant for higher education in Bachelor of Engineering courses in Brazil. Other studies also showed agreement with the analysis by (Farias 2023), demonstrating that many faculty members repeat the same pedagogical practices that were used in their education, despite significant time differences between their education and their teaching role (Dantas, 2011).

Telles also brings these pedagogical considerations to the universe of today's engineer, showing the real need for engineers to achieve some competencies mentioned by (Bazzo & Pereira, 2006) and (Milititsky, 2006) such as: applying scientific, mathematical, technological, and instrumental knowledge; conceiving, designing, and analyzing systems, projects, and products; ability to identify, formulate, synthesize, and solve problems.

In the same vein of a University Teaching context, (Zabalza 2004, apud in Dantas 2011) discusses a little about the individual character of the development of the work of faculty members within the institution, and that, over the academic trajectory, professionals are forming facing the challenges of personal life and profession.

The problem itself amplifies when there is resistance to participating in faculty training or improvement programs. This turmoil ends up being a reflection of the academic environment itself, which has not valued competent teaching as essential (Dantas, 2011).

The teacher-student binomial has in itself and in its formation complicating factors that make the process more difficult in the pedagogical field. In this context, the present work aims to collect pertinent data through a mapping of the courses of the School of Engineering of Volta Redonda (EEIMVR), in order to understand the profile of the student and the teacher and through a joint analysis, understand the progress of the implementation process of active methodologies by the school.

The theme will be important because it will bring significant results about the pedagogical area of EEIMVR, and will enable the formulation of specific improvements in the field of teaching, which encompasses all courses, with an impact for all students.

## 2 Materials and Methods

A survey study was conducted using electronic questionnaires to collect quantitative data from a representative sample of teachers and students from EEIMVR. Seventy students from different periods and courses, as well as 89 teachers representing various departments of the school, participated. Google Forms was used as the data collection tool due to its accessibility, ease of question formulation, and automatic graphic resources. The questionnaires were anonymous and included a request for authorization to use the responses in research. Due to its characteristic of visual non-identification, the form did not need to be submitted to the Research Ethics Committee (CEP), in accordance with Art. 1(V) of Resolution No. 510 of April 7, 2016. However, they were sent to the school's management for approval by the director.

Teachers from the EEIMVR Engineering Education Research Group conducted pre-tests of the questionnaire to evaluate the format and understanding of the questions by the respondents. Since the teachers were from the same target audience as the population samples, they were considered qualified for this evaluation. After receiving the questionnaires, the testers provided feedback and suggestions for modifications. Relevant changes were made, resulting in the final version of the questionnaire, which was semi-structured, including closed and open-ended questions. The Likert scale was used to assess the degree of agreement or disagreement of the respondents. Additionally, the questionnaire contained multiple-choice questions.

Two surveys were conducted, one directed to the teachers and another to the students of EEIMVR, aiming to compare their perceptions of the methodologies and pedagogical practices in the institution, especially those related to active learning. The questionnaires addressed sections such as Respondent Profile, Teaching at the University, Pedagogical Strategies, Relationship with Students, and an additional section for teachers about their Area of Education and Performance. Specific terms of active methodologies were not used, opting for questions that indicated the use of these approaches, even if the participants were not familiar with them by name. The survey was disseminated personally, with the assistance of some teachers and QR codes designed to facilitate respondent participation. The data were analyzed in three thematic sections: Teaching Practice and Scientific Research, Importance of Pedagogical Practices, and Relevance of Industrial Experience.

## 3 Results and Discussion

### 3.1 Professors' Profile

The research revealed that the majority of respondents are male (58.8%), while 38.2% are female, with a small portion (2.9%) choosing not to disclose. The male predominance was also noted by the teachers interviewed in another study (Dantas, 2011). This male dominance reflects the historical gender preference in the engineering profession, especially in urban and industrial environments. The predominant age group of the interviewed professors is 30 to 50 years old (79%). Over 90% of the teachers hold a doctorate, suggesting a high level of qualification, possibly related to the requirements for working in public universities in Brazil. Additionally, the research evaluated the pedagogical updating of the teachers, seeking to understand their interest in the continuous improvement of teaching practice, especially regarding the use of active methodologies, which encourage the experimentation of new strategies for more engaging learning. The analysis of teachers' responses regarding their pedagogical updating revealed interesting patterns.

The majority of participants (84%) are undergoing updating processes, either through remote activities (39.4%), frequent readings (36.3%), or in-person events (9.1%). Approximately 12.1% reported being unaware of some of the university's training offerings, while the same proportion (12.1%) showed little interest in pedagogical specialization. These results highlight two issues: lack of information about available courses and disinterest in the pedagogical area, which can exacerbate educational problems, as pointed out by (Dantas 2011). The possible undervaluation of pedagogical updating in university teaching may be linked to the emphasis of teachers on scientific research, to the detriment of teaching. Behrens (1998) suggests that this difficulty in motivating teachers reflects an academic environment that does not value such practices, evidenced by the preference for participation and publications in events and scientific research. The engineering professor has little incentive to engage in events and publications in the educational field.

### 3.2 Students' Profile

The results showed that 39.4% of respondents are female, a percentage similar to that of the interviewed professors. This indicates that male predominance occurs not only among the faculty but also among the students. Most students (85%) are between 18 and 26 years old. Compared to the professors, these numbers reveal a relatively large generational gap among the respondents.

### 3.3 Teaching at the University

In order to facilitate understanding, the text was organized into three thematic sections: Teaching Practice and Scientific Research, Importance of Pedagogical Practices, and Relevance of Industrial Experience. Each of these sections examined both the perspective of teachers and that of students. The numbers one to five presented in the following figures represent the degree of agreement of the respondents: 1 - Strongly Disagree, 2 - Disagree, 3 - Neither Agree nor Disagree, 4 - Agree, 5 - Strongly Agree.

a) Teaching Practice and Knowledge of Scientific Research

The results of Figure 1 reflect the opinions of students and teachers on two questions: the relationship between experience time as professor and the quality of classes, and the knowledge about the research conducted by the professors.

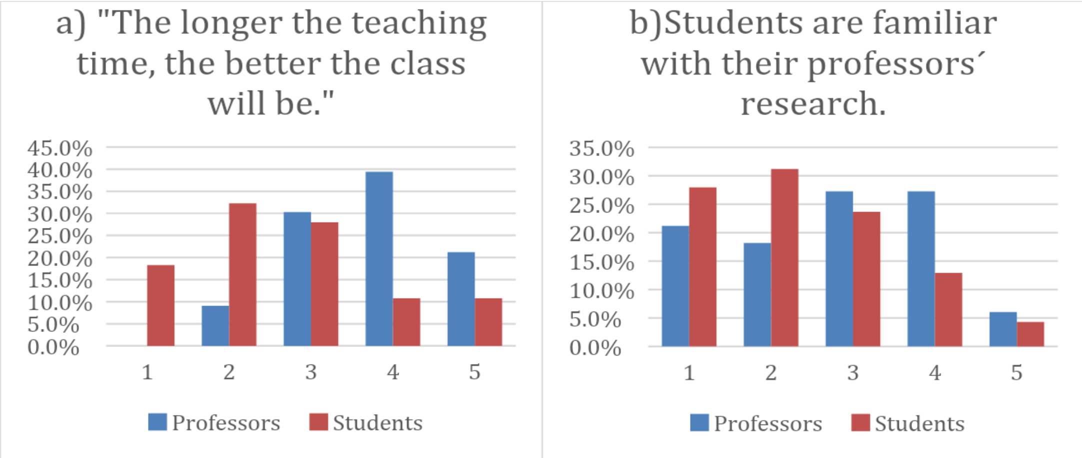


Figure 1. a) Teaching Practice and b) Knowledge of professor's research

The majority of professors (60%) value experience time as crucial for teaching, aligning with previous studies (Zabalza, 2004) indicating professional development of teachers through facing challenges, including in the classroom. On the other hand, only 20% of students consider experience teaching time crucial, reflecting different perspectives on experience. While students compare professors to each other, the teaching staff forms their perception based on their own background.

The importance of teacher training and updating is highlighted, as simply adopting a methodology for a long time does not necessarily make it better, and old lesson plans may not be effective due to generational changes (Rocha et al., 2018).

Figure 1b reveals that the majority of students disagree with knowing about teachers' research, indicating little knowledge about their research areas. Integrating scientific research into teaching practice through active methodologies like PBL may encourage teachers to incorporate research elements in the classroom, promoting a deeper understanding of concepts and stimulating students' scientific curiosity.

A suggestion of greater integration of scientific research with teaching at EEIMVR, highlighting the importance of creation of collaborative environments among professors to share experiences and adopt new teaching methodologies. Students' knowledge about teachers' research can foster closer relationships between them, making research areas more known and applied in specific disciplines, in line with National Curriculum Guidelines.

b) Importance of Pedagogical Practices

The results from Figures 2a) and 2b) reveal that both students and professors agree that teachers need to update themselves and consider research in the field of teaching important. Regarding the relationship between research and teaching, illustrated in Figure 2c), the majority of teachers and students do not consider research more important than teaching. However, teachers show greater engagement with research, which may be reflected by incentives since the hiring process and during careers where scientific production is more valued compared to teaching. (Cunha, 2006).

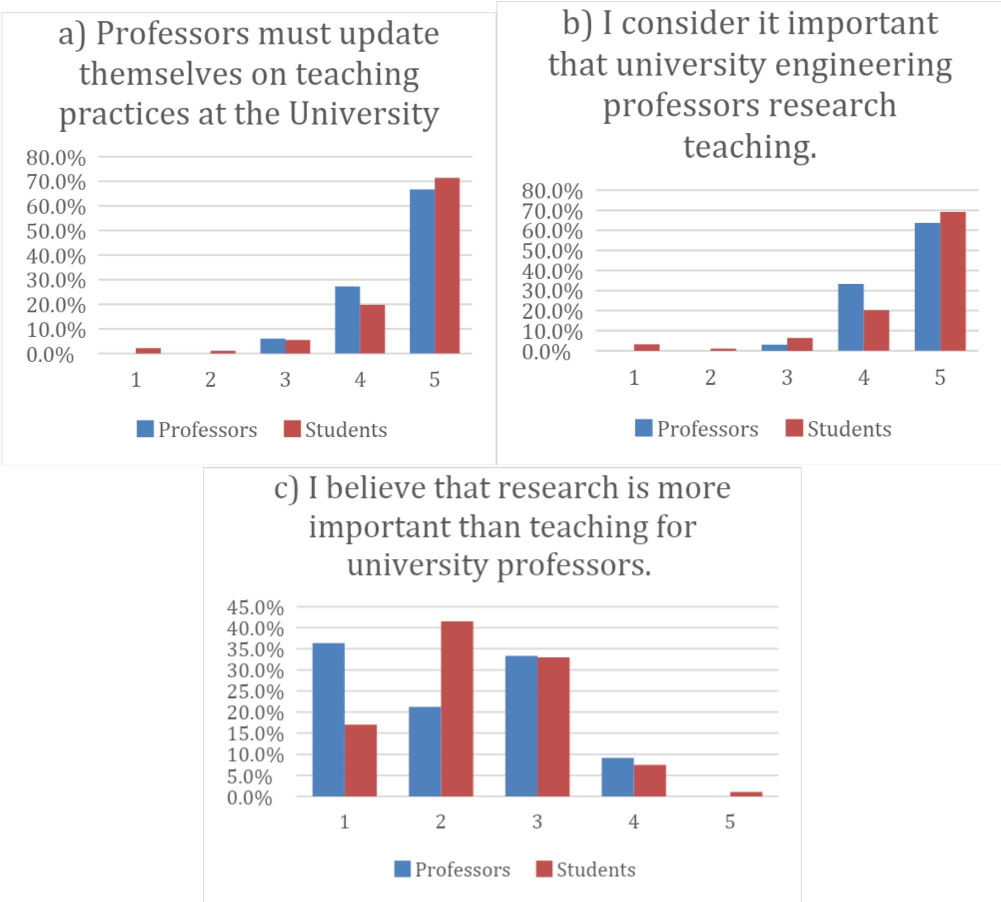


Figure 2. a) Update of pedagogical practices. b) Importance of researching new practices. c) Comparison of research and teaching.

## 3.4 Used Methodologies

This section addresses the inquiries posed to both groups to identify the use of active teaching-learning methodologies.

The results revealed a variety of methodologies in the classroom, perceived by both students and teachers. The majority of teachers (84.5%) consider their lectures highly participatory, whereas for students (72.5%), this participation is limited. This disparity may be related to the perception of active participation or its frequency. The research did not address the frequency of the use of practices in class, leaving room for a variety of reported experiences. Additionally, it was not assessed whether teachers fully master the methods, their application, and evaluation, which directly influences the results, as discussed by (Ribeiro,2002). Regarding the use of audiovisual resources, the majority of teachers (93.9%) utilize them, but merely providing technology does not guarantee a significant change in learning. It is essential to empower teachers to use these tools effectively and innovatively, which requires continuous pedagogical training to develop skills and effective strategies (Behrens, 2010).

## 3.5 Pedagogical Practices of Teachers

In this section, an analysis of the use of active methodologies is shown regarding the professor's perception of their role in the teaching-learning process. Figure 3 a) refers to the teacher's perception regarding knowledge transmission, and Figure 3 b) illustrates the teacher's perception regarding Teaching and Learning Assessment.

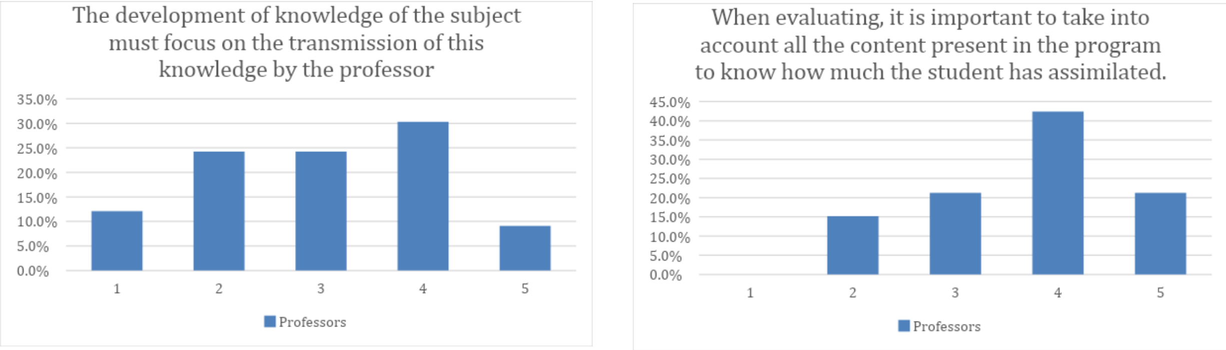


Figure 3.Professors' perception a) regarding the transmission of knowledge regarding b)Teaching-Learning Assessment.

The results reveal a lack of consensus among teachers, with some maintaining a traditional view of teaching, where the teacher plays a central role in the teaching-learning process, while others recognize the importance of Active Learning centered on the student. Studies, such as Silva et al. (2019), demonstrate better learning outcomes with active methodologies compared to conventional methods. Finally, it is important to highlight that this active learning approach is integrated into the new National Curriculum Guidelines (DCN) for Engineering courses in Brazil, aiming to encourage students to seek their own knowledge and engage in research environments with guidance from the teacher. The results in Figure 3b reveal the perception of assessments. The majority of teachers (60%) agree that assessments should cover the entire content of the discipline to evaluate student assimilation.

It is important to mention the emphasis placed on student competencies by the new National Curriculum Guidelines (DCN's), which propose not only to assess knowledge but also how closely that engineering student approaches the competencies required of a modern engineer. Therefore, it is indispensable for the teacher to consider evaluative methods that check the development of such competencies. Hence, the importance of designing and structuring such methodologies in a and intentional, for greater student learning.

Considering that the relationship between student and professor has a strong influence on the learning process, this part of the research considered the social aspect, student interest, and low performance in evaluations. These points were used to understand the perception of both students and teachers on this aspect. The results regarding the social aspect are presented in Figures 4 a) and b).

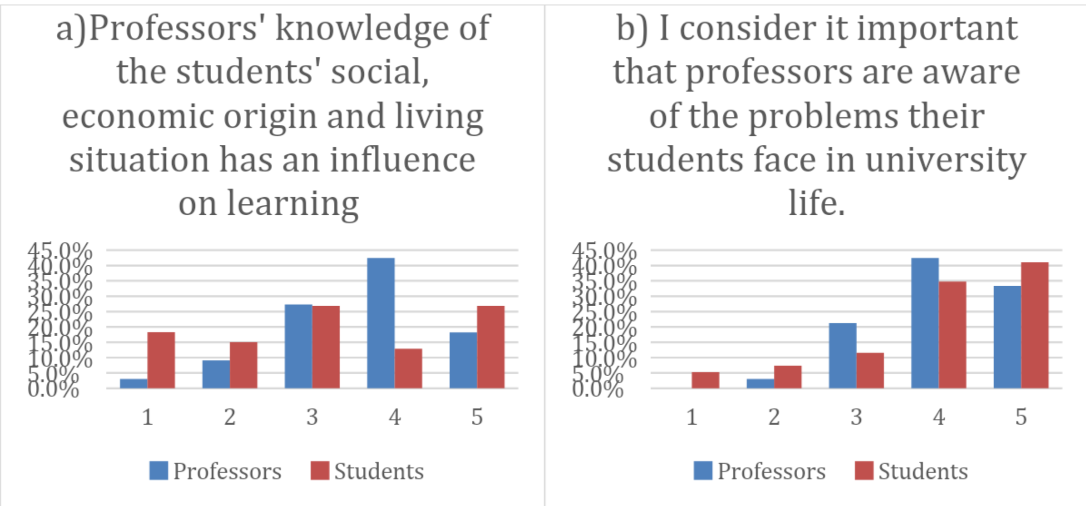


Figure 4. a) Knowledge of the students' social situation. b) Knowledge of the students' problems.

About 60% of the professors' respondents partially or fully agree that knowledge of students' social, economic background, and life situation influences learning. The results from the students were more varied, but the majority agree. This contrasts with previous studies (Dantas, 2011), indicating a shift in teachers' perception, who now value the social aspect of students more. Figure 4 b) shows that the majority consider it important for teachers to know the problems students face. These results reflect coherence and a greater interest from teachers in this theme, with over 80% showing attention to it. Studies by (Gil, 2018) highlight the importance of the teacher-student relationship for learning.

The results regarding low performance on assessments are presented in Figures 5. There is a different perception between students and teachers: students do not believe that teachers are concerned about low performance, while teachers claim to take measures in these cases. The lack of dialogue between teacher and student may explain this discrepancy.

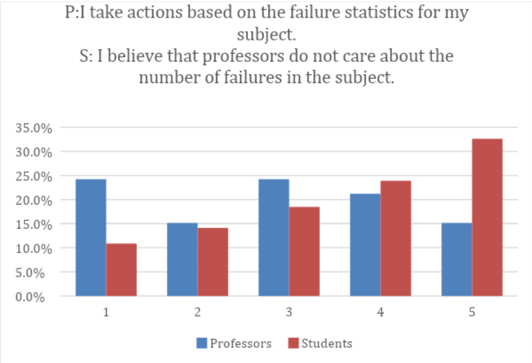


Figure 5. Perception of performance on assessments.

## 4 Conclusion

The study highlights the importance of professors seeking pedagogical update courses to meet the demands of the university context. According to the results presented, it is clear that many professors are using active methodologies in response to new curricular guidelines. Since it was not evident to the authors what the respondents' initial knowledge of active learning methodologies was, the research used general terms instead of specific nomenclatures like "Project-Based Learning" and "Flipped Classroom." The research indicates that Active Learning is well received by both professors and students, suggesting the continuation of these practices to increase student motivation and interest. A balance between traditional and active methodologies is recommended to improve student engagement. Effective communication between professors and students is highlighted as a crucial element for the development of active methodologies and the improvement of the academic environment. Overall, the results suggest a favorable context for the systematic and structured implementation of active methodologies at EEIMVR. Additionally, professors showed openness to training courses, indicating that even those with less knowledge on the subject recognize that student-centered learning is fundamental for training engineers with the skills required by the current market.

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# Active Learning in Construction Management Capstone Projects: Bridging Theory and Practice

Silvia J. Tijo-López[1], Guillermo Mejía-Aguilar[1]

[1] Universidad Industrial de Santander, School of Civil Engineering, Bucaramanga, Colombia

Email: silvia.tijo@uis.edu.co, gmejia@uis.edu.co

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**Abstract**

Construction engineering and management is a complex field that involves technical and managerial dimensions, such as project planning, structural design, construction processes, legal frameworks, and environmental sustainability. Each facet demands a nuanced understanding and proficiency in diverse skill sets. In response to this complexity, academic programs in construction engineering must evolve to incorporate innovative learning strategies that effectively prepare students for the dynamic challenges of the industry. Active learning methodologies emerge as a cornerstone in this endeavour, offering students hands-on experiences to deepen their understanding of technical concepts and develop crucial soft skills, including communication, teamwork, and leadership, which are indispensable for success in the construction industry. The School of Civil Engineering at Universidad Industrial de Santander in Colombia, has implemented capstone projects, supported by active learning strategies, to offer students the opportunity to apply theoretical knowledge to real-world scenarios using innovative methodologies such as Building Information Modelling (BIM) and sustainability features. By engaging in capstone projects, students not only develop practical skills but also gain valuable insights into emerging industry trends and challenges. This article presents our experiences in developing capstone projects and their role in bridging theoretical concepts with practical applications in a dynamic learning environment. The capstone projects have helped identify students' strengths and weaknesses, areas for improvement in our students' skillsets, as well as how they adopt innovative methodologies and address emerging issues. These insights have informed ongoing curriculum reforms aimed at ensuring alignment with industry demands and promoting educational excellence. Moving forward, we are committed to further enhancing our active learning strategies and leveraging emerging technologies to provide students with the comprehensive preparation needed to succeed in the dynamic field of construction engineering and management.

**Keywords**: Active Learning; Capstone Projects; Engineering Education; Learning Methodologies; Project Based Learning.

## 1 Introduction

Emerging technology, complex problems, collaborative environments, among other features, characterize the engineering practice and lead engineering students to acquire project-environment and problem-solving skills (Hassan et al., 2011). In fact, some authors argue that problem-solving skills, communication, and teamwork are essential for engineers to succeed in their careers (Passow & Passow, 2017). In this sense, accreditation processes, such as the Accreditation Board of Engineering and Technology (ABET), promote the development of engineering practice skills in accordance with the institutional mission, educational objectives, student outcomes, curricula, and assessment methods (Mejía-Aguilar et al., 2020).

Active learning is an innovative pedagogical approach that promotes student-near environment to implement hands-on projects, where they develop skills and competencies such as problem-solving, team collaboration, effective communication, and decision-making, among others (Xu et al., 2019, 2022). There has been an interest on the part of educational institutions, educators and industry in implementing the capstone-design or integrative project, as an active learning activity of corner design experience (Zheng et al., 2021). Design experiences encourage multidisciplinary collaboration and teamwork, in order to find solutions to real-world problems related to professional practice and ensure that students can perform effectively in a team, to work collaboratively as a team (Parker et al., 2019).

Because a excel professional performance of engineers is essential for achieving project success, the professional training of students must be guaranteed with the development of competencies and skills related to design and construction experiences. However, authors highlight some shortcomings that affect the professional performance of engineers are lack of collaborative work experience, assertive communication problems and absence of leadership when assuming assigned roles within a team work stand out (Dillon & Cheney, 2009). This situation is due to the fact that students focus only on completing their tasks no matter how it is done, which often limits the development of comprehensive knowledge and promotes the acquisition of fragmented and incomplete knowledge (Jones & Tadros, 2010).

Although it is important to implement capstone design type courses within project-based engineering programs, questions arise in practical life related to bridge theory and practice, the pedagogical approaches, methods and strategies, the development of skills and curricular issues. The answers to these questions and others related to capstone design would provide some guidance for implementing pedagogical and curricular strategies in engineering programs. Therefore, the purpose of this paper was to analyze and discuss experiences in developing capstone projects and their role in bridging theoretical concepts with practical applications in a dynamic learning environment. The capstone project was implemented at the School of Civil Engineering at Universidad Industrial de Santander in Colombia, supported by active learning strategies, to offer students the opportunity to apply theoretical knowledge to real-world scenarios using innovative methodologies such as Building Information Modelling (BIM) and sustainability features.

## 2 Active Learning and Capstone Design

Active learning plays a pivotal role in enhancing the capstone design experience for students in engineering education. By shifting the focus from passive reception to active engagement, active learning fosters deeper student involvement, critical skill development, and real-world application. This section explores various learning approaches and methods that leverage active learning principles to enrich the capstone design process.

### 2.1 Learning Approaches and Methods

Active learning approach enriches the capstone design experience by promoting student engagement, critical skill development, real-world application, and continuous learning and improvement. In capstone design projects, students are actively involved in solving real-world engineering problems, applying theoretical knowledge to practical scenarios, and collaborating with peers to develop innovative solutions.

Active learning is a student-centered learning approach that involve actively engaging students in the learning process through activities and experiences, rather than relying solely on traditional instructor-led lectures. This approach makes students active participants in their own learning. The emphasis of the active learning is more on learning and less on teaching, and it requires instructors to incorporate more active and student-centered learning methods into their courses. These methods include: Learning Factory (Lamancusa et al., 2008); Project-based learning (PBL) (Wang et al., 2012); Problem-Based Learning (Dunnigan et al., 2020); Experiential learning (Bailey & Debartolo, 2007); Collaborative learning (Xu et al., 2022); Flipped classroom (Lewin & Barzilai, 2017); Socratic Method (Golanbari & Garlikov, 2008); Enquiry-guided project learning approach (Khraisheh & Benyahia, 2012); and Hands-on, team-oriented learning (Building-as-lab concept) (Goldberg & Rank, 2013).

## 2.2 Skills Development

Capstone design projects combined with active learning methodologies facilitate the development of professional and design skills essential for engineers. Through active learning, students are encouraged to think critically, analyze problems from multiple perspectives, and collaborate effectively with their peers. These skills are invaluable in tackling complex engineering challenges encountered in capstone design projects and in professional practice. These professional skills include: Teamwork (Hanus & Russell, 2007); Diversity (Hanus & Russell, 2007); Leadership (Hanus & Russell, 2007; Lamancusa et al., 2008); Communications (Hanus & Russell, 2007); Problem-solving (Dunnigan et al., 2020); Critical thinking (Golanbari & Garlikov, 2008); Ethics (Santi, 2000); and Design thinking (Goldberg & Rank, 2013).

## 2.3 Curriculum and Administrative Issues

Active learning in capstone design projects emphasizes real-world relevance and application of engineering principles. By engaging in hands-on, project-based activities, students gain practical experience and learn to apply theoretical knowledge to solve authentic engineering problems. By integrating active learning throughout the curriculum and aligning it with the objectives of capstone design projects, educators can provide students with a rich and transformative learning experience. This learning approach sometimes generates curriculum and administrative issues such as:

- Striking a balance between theoretical concepts and practical skills.
- Managing the increased workload for professors.
- Coordinating logistics and scheduling for seamless project execution.

# 3 Methodology

This study is based on a qualitative analysis of Capstone Projects conducted in undergraduate construction management courses within the School of Civil Engineering at Universidad Industrial de Santander (UIS). These projects have been implemented across various courses, particularly focusing on project management courses. Although the civil engineering program at UIS emphasizes areas like structural design and water resources, there are few mandatory courses in project management. Therefore, managing these projects allows for the integration of various areas while fostering new knowledge among students.

The development process of the capstone project has evolved over several semesters, accumulating lessons learned along the way. Students are divided into groups of five or six students to develop the project. Starting from architectural and structural drawings of a building, students model the building using the Building Information Modeling (BIM) methodology and considering ISO 19650 specifications. Additionally, sustainability aspects not initially included in the drawings are addressed by approximating with the EDGE Green Building Certification application. The team also conducts an approach to site localization and market studies. Deliverables include finished models, sets of plans, quantity estimations, project scheduling for construction duration estimation, and project budgeting for cost estimation. Groups must demonstrate evidence of collaborative work and make oral presentations at partial submissions and a final presentation with posters. This showcases the development of soft skills such as teamwork and oral communication.

Given that the UIS civil engineering program lacks a BIM course, the project is overseen by a main course and a weekly BIM workshop. Attendance at the workshop is not mandatory, but classes are broadcasted live for student convenience, and recordings are available for consultation. The workshop schedule aligns with topics covered in the theoretical class. Table 1 presents a workshop schedule for the Construction course.

Table 1. BIM Workshop Schedule.

| | Scope | | | | | | | Time (Schedule) | | | | Cost (Budget) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Week** | **W1** | **W2** | **W3** | **W4** | **W5** | **W6** | **W7** | **W8** | **W9** | **W10** | **W11** | **W12** | **W13** | **W14** | **W15** |
| **Topics** | Course Introduction Presentation of project scope and schedule | Introduction to BIM software ISO 19650 standard presentation | Terrain modeling | Structure modeling (Foundation and superstructure) | Architecture modeling | Architecture modeling Stair modeling | Generation of Plans | Obtaining quantities from a BIM model | Reading hydraulic, sanitary, and electrical plans | Introduction to sustainability - EDGE app Energy and water consumption | Hydraulic and Electrical networks modeling | BIM coordination | Integrating times and costs with the model | Rendering and Poster | |
| **Deliverables** | | | | | | | Delivery 1 | | | | Delivery 2 | | | Delivery 3 | |
| **Oral Presentation** | | | | | | | | Presentation 1 | | | | Presentation 2 | | | Final Presentation |

# 4 Results

The capstone project in the Construction management area has been developed over five consecutive semesters of senior students. In this process, the project has undergone changes because of observations and results. The capstone project promotes active learning since the student must seek answers to real problems outside the classroom, which requires using critical thinking, applying knowledge acquired during the career, and making decisions to find effective solutions.

## 4.1 Bridging theory and practice

The field of construction management faces challenges in integrating theory with practice. Simulating construction processes in educational settings is difficult, and even more so is carrying out real projects due to the scarcity of field trips and site visits. These limitations are partly due to the size of student groups and safety concerns at construction sites. An innovative approach to bridging this gap between theory and practice is through Capstone Projects using BIM. Here, deliverables such as plans, specifications, scheduling, and budgets provide an opportunity to link theory with the reality of construction.

Integrating BIM methodology into these projects allows students to model buildings, identify properties of elements, and gain a better understanding of project complexity. Additionally, BIM tools streamline the procurement of quantities for project development. The inclusion of sustainability elements is facilitated by intuitive applications like EDGE Green Building Certification application, which provide information without the need for complex design programs.

## 4.2 Strengths, weaknesses, and areas of improvement

The Capstone Project has allowed us to identify strengths and weaknesses in our undergraduate students. In the technical component, it has served to confirm that UIS Civil Engineering students have a strong foundation in Structural design, while weaknesses have been found in other areas of the program. This has led to proposing curricular reforms for the program and revising study plans. Additionally, areas for improvement have been identified in soft skills such as oral and written communication, as well as other aspects of collaborative work.

The most important lessons learned in formulating the Capstone project are presented below:

**Team formation:** Students autonomously form teams based on preferences, with a designated team leader responsible for deliverables. Team based on preferences have better performance that teams assigned by instructors.

**Partial Submissions**: Each semester, students are required to make three submissions, comprising two partial submissions and one final submission. This structure fosters continuous progress and allows for timely feedback. Initial Capstone Projects lacked partial submissions, resulting in unforeseen final submission quality. Partial submissions facilitate corrections and establish timeframes for progress.

**Evidence of Team Collaboration:** To cultivate teamwork skills, evidence of collaborative work is mandated. Students are instructed in utilizing platforms such as Trello or Task App for Microsoft Teams. An example of the evidence of team collaboration using Trello is displayed in Figure (Left).

**Display of Work Schedule:** Despite emphasizing project execution planning, student groups often exhibit reactive task completion as deadlines loom. Requiring documentation of the work schedule ensures an understanding of the time required for project completion. Figure 1 (Right) shows an example of work schedule for project completion using Microsoft Project.

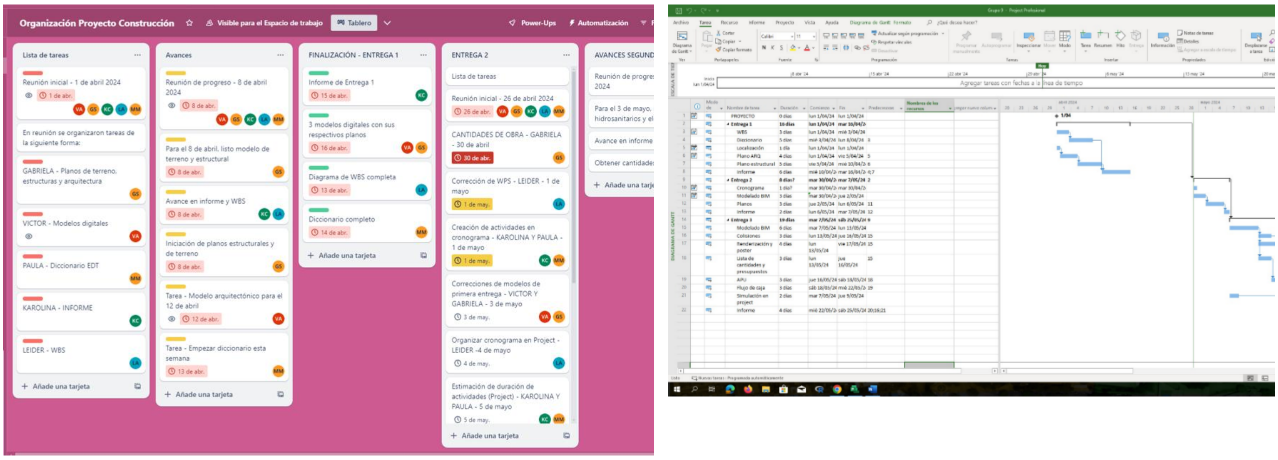


Figure 1. Left: Team collaboration using Trello. Right: Work schedule

**Clarity in Submission Requirements:** Clear and precise statements are essential to ensure comprehensive delivery of required information, facilitating review and grading. Table 2 shows an example of the requirements for the first submission requirements of the capstone project.

Table 2. Capstone project- Submission requirements.

| Item | | Description | Percentage |
|---|---|---|---|
| Item 01 | WBS | A schematic WBS [in Project or other similar software] | 40% |
| | | Propose at least three levels of the WBS | |
| | | The breakdown must be done considering what was covered in class | |
| | | The last proposed level should allow tracking of work progress [work packages] | |
| | | Define the dictionary only for the last level of breakdown [work package] according to what was seen in class | |
| | | Define in the dictionary the scope of each work package by describing the main activities that make up each work package, the units of measurement of the related activities, and the characteristics of the product to be delivered for each activity. It should also relate to the technical specification of each activity, as a first estimate of the duration. | |
| Item 02 | 3D Model | Model created in BIM Buildings with earthworks movements | 30% |
| | | Model created in BIM Buildings with the structural system | |
| | | Model created in BIM Buildings with the architectural system | |
| Item 03 | Drawings | Site plan | 20% |
| | | Architectural plan | |
| | | Structural plan | |
| Item 04 | Report | A written report to support the assumptions, considerations, and calculations made. | 10% |

**Oral Presentations:** Oral presentations enhance communication skills and provide opportunities for clarifying points not covered in written documents. Both slide and poster presentations serve distinct purposes. Figure 2 (Left) shows an image of a team during their presentation.

**Utilization of Templates and Examples:** Templates offer students guidance on presenting specific information, enhancing submission quality. The templates are giving to students during the semester, and example of a template is shown in Figure 2 (Right).

Figure 2. Left: Oral presentations. Right: Template for drawings

## 5 Conclusion

In conclusion, active learning methodologies, particularly through capstone projects, serve as a bridge between theoretical concepts and practical applications in construction engineering and management education. These projects, supported by using active learning strategies and methodologies like Building Information Modelling (BIM) and sustainability features, offer students hands-on experiences to apply theoretical knowledge to real-world scenarios. Despite the evident benefits, implementing active learning approaches in the curriculum can present challenges, including balancing theoretical and practical components, managing increased professor workload, and coordinating logistics for project implementation. However, addressing these challenges is crucial for ensuring the effectiveness of active learning initiatives and preparing students adequately for the dynamic demands of the construction industry. Through continuous assessment and curriculum reforms, educational institutions can strive towards providing students with comprehensive preparation and fostering their success in the field of construction engineering and management. By leveraging active learning strategies and integrating emerging technologies, educational institutions can create transformative learning experiences that equip students with the necessary skills and competencies for successful careers in construction engineering and management.

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# Ethics through the Curriculum of the Faculty of Engineering

Carola Hernández Hernández[1], Nicolás Sánchez-Díaz[2]

[1] Profesora Asociada, Unidad de Apoyo a la Docencia, Decanatura, Facultad de Ingeniería, Universidad de los Andes.
[2] Asistente Graduado de Investigación, Unidad de Apoyo a la Docencia, Decanatura, Facultad de Ingeniería, Universidad de los Andes.

Email: c-hernan@uniandes.edu.co, n.sanchezd2@uniandes.edu.co

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**Abstract**

Engineering education in the 21st century faces significant challenges due to changes related to sustainability, globalization, the use of information and communication technologies, and complex social problems that require reviewing the role of engineers in society. One is the analysis of engineering solutions' social, environmental, and cultural impact, which is a critical element for achieving the Sustainable Development Goals, and the reflections on professional ethics derived from this.

Engineering faculties are responsible for identifying educational options to ensure that their students develop the skills expected of them. Ethical competence dynamically articulates knowledge, know-how, and being with the specific aspects that make up ethical action (Montoya & Santiago, 2024). However, a long tradition of understanding engineering ethics as an individual matter and following codes of professional obligations (Lee et al., 2019; Gwynne-Evans et al., 2021; Mitcham, 2009) implies a challenge to the broader view of the competition.

This document uses a case study to present the proposal of the Center for Applied Ethics of the Universidad de los Andes proposal around the teaching of ethics through the curriculum in the Faculty of Engineering, identifying the achievements and challenges this process has faced throughout its implementation. The document presents, in addition to a historical perspective of the role of ethics in engineering and its education, the development of the mainstreaming of ethics as the ideal of the work of ethical competence, recognizing the participation of teachers and the review of the micro-curriculum as a contribution to the process.

**Keywords:** Ethics across the curriculum; Engineering education; Ethical perspective; Teachers' development.

## 1 Towards a historical perspective of ethics in engineering

When conducting a historical review of the relationship between ethics and engineering, the causal effect between the role of engineering practice and its assumed ethical perspective in a given context can be evidenced. Mitcham (2009) provides a historical account of the vision of ethics in engineering in the United States, which can be organized into four stages.

In its first stage, which includes the period between 1600 and 1800, ethics within the engineering framework are characterized by obedience to social hierarchy. This respect is directly linked with the predominant military values of the time and social relationships established from hierarchical power.

This characterization of respect or subordination remained in force until the first decades of the 20th century, when the second stage of professional engineering development would occur. This second moment was characterized by the emergence of ethical codes from various engineering associations; the codes of the American Institute of Electrical Engineers (AIEE) appeared in 1912, and the ethical codes of the American Society of Civil Engineers (ASCE) and the American Society of Mechanical Engineers (ASME) appeared in 1914.

In this historical period, loyalty was in the public interest, and the public good was directly related to fidelity to the company. The previously mentioned codes made explicit the guidelines for protecting the interests of the client and the employer. Social welfare was understood as the welfare of the company.

Simultaneously with the appearance of engineering associations, which comprises the third stage, the objective of technical perfection and efficiency appears at the center of the discussion of engineering work. In this way, questions are introduced around the unequivocal fulfillment of employers' commercial interests to give rise to their own standards of good and wrong from technical criteria that allow the generation of better products.

From this, the paradigm of technical development is assumed to be a path for human progress. However, this resulted in technical decisions becoming the primary purpose of engineering, creating final products that did not necessarily contribute to the generation of social welfare.

The scene of the end of World War II and the geopolitical contexts of the Cold War bring with them a new ideal of ethics in engineering, generating an alternative to the perspectives of loyalty and efficiency by focusing their analysis on the social effects of engineering interventions and the adjacent responsibility to the profession. This sets up the fourth stage, characterized mainly by recognizing the importance and social implications of the professional role of engineering. Following this, Figure 1 graphically summarizes the historical timeline described so far.

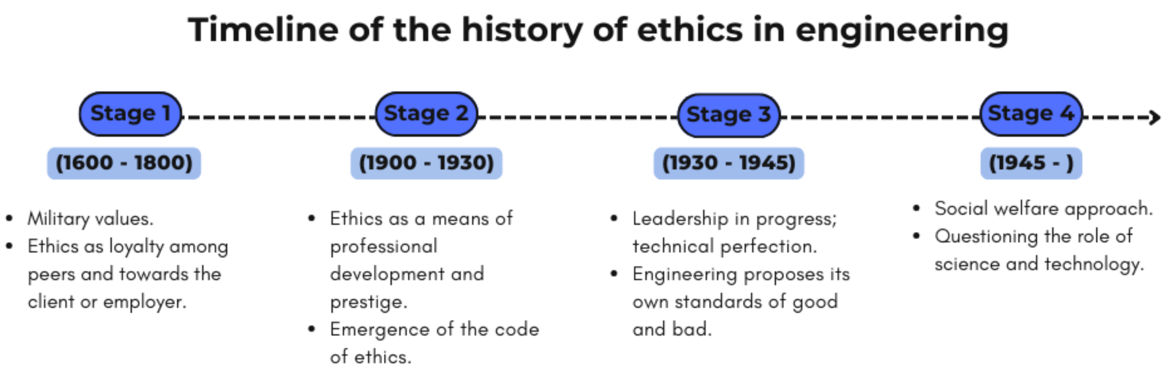


Figure 1. Engineering ethics timeline. Own elaboration based on Mitcham’s (2009l text

In the 1970s, the IEEE published its code of ethics, analyzing the impact of engineering on people’s lives. In other words, the code proposed that the ethical development of engineering works contemplated responsibility for public welfare. On the other hand, interactions between engineering and philosophy professors increased, with discussions that revolved around the need to understand the ethical formation of engineers beyond technical issues (Mitcham, 2009).

In 1980, the Engineers’ Council for Professional Development (ECPD) reoriented its educational function towards certifying engineering programs in the United States. In this way, the Engineering and Technology Accreditation Board (now called ABET—Accreditation Board for Engineering and Technology) sought to ensure compliance with the seven fundamental canons formulated by the Engineers’ Council (Mitcham, 2009).

The United States government supported the publication of three books on ethical education in engineering in the 1980s. Thus, Albert Flores and Robert Baum, Mike Martin and Roland Shinzinge, and Stephen H. Unger managed to publish their works that addressed aspects such as reflection on case studies, historical references, the need for articulation and incidence of professional societies, social experimentation, the implications of engineering practice, among other elements.

Despite the efforts, the discussion of ethics in engineering was nothing more than a space for individual reflection on professional responsibility. With this condition, creating courses dedicated to the study of ethics in engineering was an alternative that did not appropriately, practically, and explicitly cover the ethical implications of engineering. Chance et al. (2021) conducted research in which they asked about decision-making in civil engineering, and the term ethics did not appear as a factor to consider. However, they did refer to protecting the environment and improving people's quality of life.

At the beginning of the 21st century, ABET proposes 11 expected outcomes for individuals graduating from engineering programs. Criterion 3f establishes "an understanding of professional and ethical responsibility," and criterion 3c includes some other ethical considerations: "the ability to design a system, component or process to meet desired needs within realistic limitations such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" (ABET, 2015). This explicitly called for the pedagogy of teaching ethics in engineering without the need to guide specific content and to materialize the commitment to ethical competence with a more humanistic vision of engineers beyond established codes (Beever & Brightman, 2014; Bucciarelli, 2008; Lee et al., 2019).

After implementing the first accreditation criteria in 2000, engineering faculties were encouraged to define evaluation and improvement objectives for their programs while giving them greater flexibility to achieve them. The results (Lattuca et al., 2006) showed that many programs managed to improve transversal professional skills without affecting the development of technical skills. A student-centered learning approach was adopted, using design projects, teamwork, case studies, improving feedback, and emphasizing skill development.

By the end of the 2010s, ABET decided to trim down the expected outcome criteria from 11 to 7 to train engineering professionals. Criterion 4 states that engineering professionals should have "the ability to recognize ethical and professional responsibilities in engineering practice by making informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and social contexts" (ABET, 2023). The actions proposed by ABET pose a challenge to the widespread student perspective that courses focused on ethics are of little importance compared to those that develop technical components. As the text unfolds, the contribution of the Center for Applied Ethics at Los Andes University (CEA) in driving this transformation within the Faculty of Engineering will be highlighted.

## 2 Ethics across the curriculum

From the Center for Applied Ethics at Los Andes University, an approach to Ethics across the curriculum is proposed, which, among other things, involves thinking about ethics throughout life, through the curriculum, and life through the University (Montoya & Santiago, 2020). This conception aims to understand the individual as an integral being for whom ethical reflection makes sense in various scenarios and is worth being taught explicitly. Throughout university life, the student is conceived in all their dimensions, beyond the skills associated with professional work, considering aspects that constitute the human condition.

The CEA's vision of ethics throughout the university revisits Dewey's idea that "we do not educate directly but through the environment" (Dewey, 1916, cited by Montoya and Santiago, 2020). This implies constituting appropriate contexts that allow the visibility of ethics in all university areas. Therefore, although the CEA focuses on teacher training, elements of an organizational nature and the university's social responsibility are addressed by the Vice-Chancellor of Research and Creation and the Vice-Chancellor for Development.

The work of the CEA is oriented towards a dynamic approach to the curriculum, proposed as the design of the students' educational experiences at the university (Montoya, 2013). Likewise, the university has opted for a competency-based curriculum that recognizes the complexity of educating individuals by adequately integrating knowledge, skills, and attitudes that allow them to act appropriately in various situations. Therefore, creating a curriculum that promotes ethical competence requires a link between ethical knowledge and disciplinary content with practical implications for students.

Understanding ethics through the curriculum in this way, the primary strategy is the design of Epsilon courses that contemplate that "professors of all disciplines and professions incorporate an objective of ethical training in their disciplinary course, which implies the design of a sequence of teaching, learning, and evaluation that accounts for their achievement" (Montoya & Santiago, 2020, p.193). This methodology exposes students to multiple educational experiences and the concepts of philosophical ethics through ethical deliberation tools that allow them a tangible approach to their contexts.

The great challenge this proposes is that engineering professors, as proposed by Bucciarelli (2008), stop forgetting ethics as part of their professional responsibility or express that they are not qualified to teach the subject, focusing their teaching work towards the world of objects free of values. Assuming a leading reflective role around the implications of engineering in real contexts allows the humanization of the engineer and engineering itself.

## 3 Ethical Education in the Faculty of Engineering

In 2023, the Faculty of Engineering at the Universidad de Los Andes is organized into seven departments and offers ten undergraduate programs, 19 master's degrees, four specializations, and two doctoral programs. Its mission is to educate highly competent engineers in technical, ethical, and personal aspects, enabling them to lead social transformations and improve the quality of life by transferring knowledge, technological innovation, and solution design.

Figure 2 chronologically organizes how the discussion on ethics has advanced in the Faculty of Engineering at Los Andes University. It presents the most relevant events.

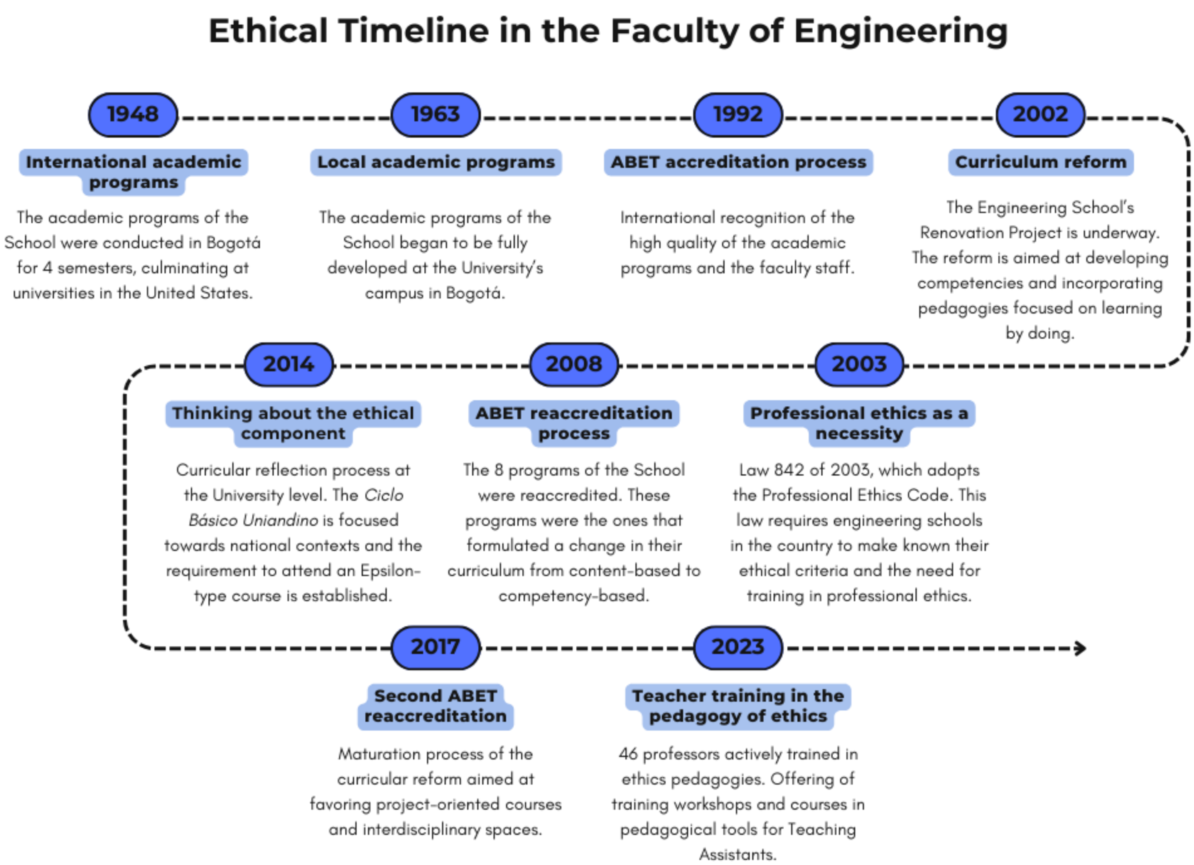


Figure 2. Ethics across the curriculum in the Faculty of Engineering of Los Andes University. Own elaboration

Throughout its history, the Faculty of Engineering has had a close relationship with the education provided in the United States (Universidad de Los Andes, n.d.). This allowed students of the Faculty to spend their first semesters in Bogotá and then travel to major universities in the United States to complete their studies. Likewise, this close link allowed the Faculty to stay updated on discussions about the quality of engineering education. The ABET accreditation attests to this.

As recorded in Figure 2, in 2002, the Faculty directed its curricular reform towards developing competencies and including pedagogies oriented towards learning by doing. These reforms took place in 2005. Simultaneously, in 2003, the Professional Ethics Code was adopted by enacting Law 842. This law obliges the faculties of Engineering to identify ways to make it known to their students and proposes, as happened in the United States, the need for an education that includes professional ethics.

After ten years without accreditation in Colombia, ABET resumed the process in the country. In 2008, the Faculty carried out the self-evaluation exercise under the 11 criteria proposed by ABET at the time. The eight programs of the Faculty were accredited. It is essential to highlight that the accredited programs reformed their content-based curriculum to a competency-based curriculum.

The CEA created the course Tools for Teaching Ethics to support the professors pedagogically. This contributed to a training scenario to reconsider the courses, strengthening their ethical component and, thus, the idea of the Epsilon courses. To date, 46 professors have been trained in ethics pedagogy in an active, student-centered, and contextualized form. This exercise allows professors to be part of the Epsilon community, where interested professors share their course design, the experiences they carry out, and the reflections that arise from these implementations, thus enriching the pedagogical reflection on the teaching of ethics.

By implementing these actions that empower professors regarding ethical aspects in their courses, students receive the correct message that facilitates their learning. From a curricular perspective, providing professors with these pedagogical tools facilitates the transformation of practices and the materialization of the logic of ethics through the curriculum (Lattuca et al., 2006).

Engineering teachers' involvement in rethinking the ethical component of their courses is related to two significant events for the faculty: Firstly, curricular reflection was carried out at the University between 2014 and 2019 (Langebaek et al., 2020). The duration was modified there, and a visible axis was established in Colombia for the Uniandes Basic Cicle (CBU). In addition to explicitly analyzing Colombian problems, a degree requirement was established, and all students must take an Epsilon-type course within their CBU courses.

Secondly, by 2017, the Faculty had developed a level of discussion and reflection that allowed it to face the ABET reaccreditation process, starting from the approach proposed by the curricular reform. At this point, the CEA's offer gained more value, and its contribution to the process was evident. It is fundamental to mention that this reform, far from seeking to unify the different departments, gave them the independence to strengthen their identity and simultaneously build the idea of the Faculty (Duque & Reyes, 2020).

The critical idea representing a structural innovation within the reform is to bet on project-oriented courses as interdisciplinary spaces. In developing these courses, students from various areas of engineering face real challenges in generating solution prototypes in the contexts of companies, organizations, and communities. For this, students must resort to many cross-competencies, among which ethical reflection gains importance through the students' analysis environment.

This project-oriented course approach allows engineering students to approach real situations in their profession's development and contemplate ethical considerations that would not otherwise be significant in their training process and lives. These scenarios address the need posed by the 21st century to expose students to tasks beyond solving a given problem and present them with a real scenario in which problems do not arrive as an exercise to be solved in a book. However, it is the same interdisciplinary interaction that allows for the characterization of a situation as problematic, as well as finding within this deliberation the ethical implications of the intervention of each discipline (Figueiredo, 2021).

Aligned with this course perspective, the Vice-Chancellor of Research and Creation conceptualized the π (Pi) type courses. These training spaces start from the context of 'learning by doing' and seek to strengthen the skills associated with the research/creation of students (Universidad de Los Andes 2, n.d.). Within the teaching team that supports these courses, a doctoral student acts as a tutor, supporting the course's research and bringing aspects of research ethics to the discussion.

While Epsilon professors lead many project-based courses in the Faculty, they are not necessarily labeled as such. In fact, based on their characteristics and research focus, they could be considered Pi-type courses. However, the presence of professors who have developed training processes around the teaching of ethics allows ethical reflections to be more articulated with the contents and learning objectives of the sessions within the implementation of the courses.

Within the Faculty of Engineering, the Vice-Chancellor of Research and Creation established the Faculty's Ethics Committee (Universidad de Los Andes 3, n.d.). This made explicit the requirement to analyze the ethical implications of the research carried out by faculty members. For this, the committee has developed some tools that guide the review process and provide a step-by-step approach, starting with a self-classification of risk exercise for the research.

Within the follow-up on Ethics across the curriculum in the Faculty, the CEA has been articulated with the Engineering Education Support Unit. In addition to strengthening and expanding the offer of training processes in teaching ethics, it has been possible to accompany the development of the courses more effectively. At this moment, the Faculty has five CBU Epsilon-type courses.

As part of the Faculty of Engineering's Exemplary Teaching Plan and within the faculty's training process offer, the Teaching Support Unit has designed a series of strategies to favor the training processes of faculty professors at all levels. This includes Teaching Assistants for Master's and Doctoral degrees, Chair professors, and Plant professors.

For the Graduate Teaching Assistants of the Master's degree, those Master's students who accompany undergraduate engineering courses and develop teaching tasks, a cycle of training workshops in pedagogical tools was proposed. Within this cycle, one workshop addresses ethical reflections on engineering and the teaching role. An average of 80 students take these workshops each semester.

The Pedagogical Practices Seminar course is offered annually to doctoral students in charge of courses. This 16-week course seeks to foster spaces for discussion and reflection on the pedagogical exercise. Ethical implications are evidenced throughout the course from teaching work and engineering interventions. In addition, one of the sessions is led by the CEA, focusing specifically on the theoretical and practical recognition of ethical analyses in engineering. On average, 12 doctoral students attend this course annually.

# 4 Challenges of the Ethics Across the Curriculum of the Faculty of Engineering

Ethical training in engineering represents a significant challenge in itself as, among other things, it implies thinking of engineering as a task whose social impacts must be analyzed and considered in decision-making. This document presents the evolution of ethical interpretation in engineering, starting from loyalty to the client and commercial subordination, passing through the optimization objective to arrive at a direct relationship with social well-being.

For the Faculty of Engineering at Los Andes University, this is a significant challenge and an urgent task to face, given the ABET accreditation of its programs and the commitment to disciplinary innovation and engineering education that it represents. This Faculty perspective has involved, and will involve, great efforts throughout the maturation of the proposals and will require spaces for deep reflection and collective construction of the Faculty from the entire university community. In this sense, the contribution of the Center for Applied Ethics has allowed the establishment of dialogue scenarios among the teachers who have been contributing to this discussion and a collective action driven from the departments as autonomous spaces but always linked with the idea of jointly configuring a robust Faculty with programs that aim through explicit objectives, teaching-learning activities, and evaluation, at the disciplinary development accompanied by the development of transversal competencies.

Creating educational materials that meet the needs of the courses has revolved around recognizing local contexts and current news. In this way, the development of the courses has been situated in an ethics teaching from the context. Within the need to dialogue different criteria and interpretations of reality and thus be able to nourish ethical deliberation, the CBU courses have enriched the relationships of students from different faculties. These strategies have led the University to assume ethical competence beyond a mission statement and as a daily practice.

The autonomy of the departments that are part of the Faculty of Engineering represents a considerable challenge concerning the number of courses and how the ethical component is made explicit or outside the course objectives. The risk with this approach to proposals through the curriculum is that it is interpreted as problematic that students may be receiving different training within the same institution. Their solution perspective is to teach a homogeneous course to address specific themes and competencies. This, as evidenced in this document, does not respond to the current needs of the training required by a student in the face of ethical competence.

Continuing to strengthen the training processes and discussion scenarios among the academic community is one strategy that allows us to continue consolidating good practices and assuming the shared responsibility of ethical training in engineering. Just as we seek to permeate the student from the transversality of ethical competence, constant reflection and teacher training (within the workshops for Master's Assistants, the course for Doctoral Assistants, and Epsilon-type teacher training) becomes a priority to appropriate the ethical approach contextualized through the curriculum.

Precisely within the strengthening of training scenarios in the inclusion of ethics, it is crucial to mention at this point that, recently, the CEA has partnered with Globethics to offer the course "How to Include Ethics in University Education" (Globethics, 2024). This course addresses the objectives of ethical training, valuable tools for ethical awareness, and tools for ethical deliberation. In this way, the proposal for the mainstreaming of ethics suggested by the University of Los Andes seeks to contribute to professors and, in general, other institutions and universities to integrate the teaching of ethics throughout the curriculum.

On the other hand, evaluating this competence and monitoring its development becomes a complex task. Accustomed to evaluating performance through pre-elaborated cases and focused on theoretical aspects, engineering professors must change the paradigm to propose real scenarios in which the circumstances raised require an ethical act. One of the objectives of the Faculty is for its graduates to be recognized for their integrity, placing ethical discernment in an increasingly important place. For this reason, it is desirable to take on the challenge of proposing authentic and comprehensive evaluation mechanisms that provide us with precise and relevant information about the learning processes of the students and understand what has been achieved to think about how to improve the proposal of each of the programs of the Faculty.

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# Learning Indicators as Tools for Continuous Improvement in the Educational Environment

Dianne M. Viana[1], Cristiane S. Ramos[2], Márcia R. Mortari[3], Eduardo Bessa[4], Sergio Antônio A. de Freitas[2]

[1] Faculty of Technology, University of Brasília, Brazil
[2] Faculty of Gama, University of Brasília, Brazil
[3] Biology Institute, University of Brasília, Brazil
[4] Faculty of Planaltina, University of Brasília, Brazil

Email: diannemv@unb.br, cristianesramos@unb.br, profbessa@unb.br, mmortari@unb.br, sergiofreitas@unb.br

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**Abstract**

In today's fast-paced world characterized by rapid knowledge evolution and increasing information valuation, the education sector faces unprecedented challenges. These challenges require a continuous commitment to the evaluation and enhancement of pedagogical practices, adapting them to emerging needs and challenges. In this context, learning indicators emerge as fundamental instruments, offering detailed insights into the efficiency of active learning methods and strategies, and student progress in the development of essential competencies. This article is dedicated to exploring the implementation of two key indicators in the educational environment, aiming at optimizing the quality of teaching and learning in engineering course disciplines. The first indicator analyzed focuses on identifying students' prior knowledge and assimilating new concepts, fundamental for meaningful learning. The second indicator seeks to evaluate the consolidation of engrams, that is, the formation and reinforcement of memories related to learned concepts, allowing the identification of gaps in the teaching-learning process. It is argued that the adoption of these indicators, among others, is necessary for effective educational management, allowing not only the monitoring and evaluation of pedagogical practices but also the planning of precise and well-founded interventions to establish an inclusive, efficient, and motivating learning environment.

**Keywords**: Learning Indicators; Active Learning; Teacher Training; A3M.

## 1 Introduction

In today's fast-paced world characterized by rapid knowledge evolution and increasing information valuation, the education sector faces unprecedented challenges. These include the urgent need to integrate digital technologies into educational practices to align with the evolving professional skills required by the workforce and to improve educational outcomes at scale (Diogo et al., 2023; Fomunyam, 2019; Hattie, J., 2009).

Traditional pedagogical practices are being questioned, making it imperative to seek methods that ensure the effectiveness and relevance of education. Learning indicators, analytical tools designed to measure and evaluate specific aspects of the educational process, emerge as key elements in this scenario (Prince, 2004; Christie & Graaf, 2017; Hartikainen et al., 2019).

In this context, the Learning for the Third Millennium Program – A3M (2017) is tasked with collaborating with the University of Brasília community to identify, value, and promote innovative educational actions, aiming to provide a sustainable portfolio of methodologies, processes, and applications for use in the university's programs.

As a way to promote more effective teaching and learning strategies within the scope of the program, the calls for proposals to encourage innovative educational projects for undergraduate teaching now require the use of learning indicators to demonstrate evidence of learning gains in the final reports of the awarded projects.

This article focuses on the implementation and analysis of two specific indicators related to learning from the point of view of neuroscience, proposed by the committee that coordinates the A3M program (Ramos et al., 2023). The two indicators were implemented in two engineering program courses, involving three classes each one, in educational environments that employed variations of active learning methods and strategies. In these courses, the practical application of knowledge and the development of technical skills are prioritized, without leaving aside the soft skills, and highlighting the importance of aligning educational theory with practical demands. These approaches emphasize the need to integrate theoretical knowledge with concrete practical experiences, aiming for a more comprehensive education tailored to the demands of the professional market.

A literature review reveals difficulties regarding the systematic application of learning indicators and their impact on the continuous improvement of pedagogical practices (Prince, 2004; Christie & Graaf, 2017; Hartikainen et al., 2019). Therefore, this study aims to deepen the understanding of how specific "classroom indicators" can optimize the quality of teaching and learning, from identifying students' prior knowledge to evaluating their motivation and engagement.

By critically analyzing the potential of indicators as continuous improvement tools, this article highlights their importance for effective educational management and the establishment of an inclusive, efficient, and motivating learning environment. The goal is to illuminate the path for more informed and evidence-based pedagogical interventions, offering significant contributions to the academic community and education professionals. This approach promotes a culture of continuous evaluation and improvement in teaching practices.

## 2 Active Learning Outcomes

According to Christie & Graaf (2017, p. 11), "Constructivism, which has helped shift the emphasis in formal educational systems from a focus on the teacher to various forms of student-centred learning, has provided a basis for a number of pedagogical models." These models, in turn, can encompass instructional methods and strategies of active learning.

By placing the student at the center of the educational process and encouraging active rather than passive participation, the approaches derived from these models spark interest in improving engineering education. The effectiveness of these approaches in preparing engineering students for real professional demands has been recognized in various studies, as they facilitate the understanding and application of technical concepts and foster essential skills in problem-solving and collaboration (Prince, 2004; Christie & Graaf, 2017; Hartikainen et al., 2019).

Defining strategies to measure student progress and provide necessary feedback for formative adjustments is an important step to ensure that desired educational outcomes are achieved. An aspect highlighted by Prince (2004) involves the challenges that engineering faculty face in assessing the efficacy of active learning. Relying on empirical studies published in scientific articles, it is often difficult to understand what is being studied and how improvements are measured and interpreted, as many methods are grouped under the term "active learning". Evaluating what works may involve analyzing a broad range of learning outcomes and quantifying the reported improvements. According to the author, educational studies, although useful, have limitations and do not guarantee that the same methods will produce similar results in different contexts.

Regarding indicators used to measure the impact of active learning on student learning outcomes, Hartikainen et al. (2019) conducted a review of empirical articles, identifying associated learning outcomes and how they are measured. They found that most are based on self-reported data from students, focused on the development of course-specific knowledge, and highlight the need for studies to enhance the transparency of empirical interventions and the application of active learning.

In this context, it is clarified that the intent of this work is not to evaluate the efficacy of the active learning methods and strategies used, but rather, to characterize the learning environment utilized in the application of the presented indicators.

The strategies used in the applications are the Flipped Classroom and Peer Instruction, and the methods are Problem-based Learning and Team-based Learning. Detailed explanations can be found in Elmôr-Filho et al. (2019), Villas-Boas & Sauer (2019), and Burgess, McGregor & Mellis (2014).

# 3 Learning Indicators Based on Neuroscientific Concepts

To effectively utilize indicators based on neuroscientific concepts, it is essential to deepen our understanding in this field. This broader knowledge will support the comprehension of both the indicators themselves and their contributions to teaching. In this context, this text presents key aspects that can aid and enhance knowledge about neuroscience, specifically related to the indicators developed by the authors, based on the work of Ramos et al. (2023).

From a neurobiological perspective, learning is a cerebral process that involves acquiring new skills, marking an initial phase in the broader memory process, which includes acquisition, retention, consolidation, and recall of information. According to Izquierdo (2002), the memory process consists of these stages, where the processing of sensory, experiential, or linguistic experiences stimulates the reconstruction of neural assemblies in a constant flow of information. These abilities, whether cognitive or motor, are retained and recalled as needed.

Therefore, learning, known as the construction of knowledge, results in the integration of new information into pre-existing knowledge and requires the proper functioning of brain structures as well as an appropriate conscious state. Changes are constantly required as we are perpetually assimilating new information and electrical stimuli that travel through neurons and can be cataloged and stored in various brain regions, known as memory engrams. This remarkable ability to add new knowledge to previously consolidated information in memory, forming networks and reprocessing what has been learned, characterizes neuroplasticity.

In this context, indicator 1 was developed.

Memory consolidation is the key process that allows acquired information to be stored in neural circuits for long periods, enabling recall and adaptation over time. This process, essential for the formation of long-term memory, relies on neuroplasticity—a feature of the brain that allows it to mold and react to new information through the repetition of data and associated emotional stimuli. By leveraging neuroplasticity in educational settings, we aim to solidify this information within our students' brains, ensuring that it remains accessible and applicable as needed.

Cognitive neuroscience identifies this reinforcement of memory as the elaboration of an established mental lexicon, enriching it as new information is integrated. This involves not only learning specific terms but also their attributes and uses, which are then woven into the existing cognitive network. As new related concepts are added, this network becomes increasingly complex, enhancing students' ability to innovate and apply their knowledge successfully to future projects and professional tasks. This enriched network not only supports academic and professional success but also fosters the capability to generate novel solutions to emerging challenges.

From these concepts, Indicator 2 was developed.

Below are presented the two classroom performance indicators based on concepts from neuroscience discussed.

## 3.1 New Concept Acquisition Indicator

In this indicator, both the prior knowledge of students and the acquisition of new concepts can be identified. It is important to first assess prior knowledge to identify concepts previously acquired but necessary for the synaptic enrichment and strengthening induced by the course.

A form should be administered at the beginning and end of the semester, or before and after the completion of a module of new knowledge to be acquired.

The instructor creates a comprehensive list of prior concepts and those to be acquired throughout the course or module. The richer and more detailed the list, the more complete the instructor's understanding of the students' prior knowledge will be.

After generating the list of prior and new concepts, the instructor will present the list with knowledge markers, as indicated below:

1. I have never heard of this concept.
2. I have little knowledge.
3. I have partial knowledge about the subject.
4. I have full knowledge.
5. I have full knowledge and know how to apply it.

When assessed at the beginning of the semester, the indicator provides a list of concepts that are more widely mastered by students, while at the end of the module or semester it will indicate the percentage increase in concepts learned. This difference also helps to identify concepts that are poorly incorporated by students, as well as concepts that were greatly reinforced during classes.

## 3.2 Connection Network Enrichment Indicator

This indicator is useful for identifying the formation and enrichment of engrams, a result of neuroplastic changes, which make long-term memory more complex and recall capabilities more effective. The formation of engrams results from these neuroplastic changes. The indicator also helps in assessing which concepts have been consolidated and which still require reinforcement. It can be introduced to students at the beginning or end of the semester or module, or only at the end of the period.

The teacher presents a single key term and asks the students to list the entire network of information associated with the term. The increase in the network of connections formed over the semester or during the teaching activity is calculated. The quality of elaboration and the effectiveness of integrating correct concepts into the topic in question result in an increase in the connections made by the student. As the elaboration becomes richer and the correct concepts are more effectively linked to the topic addressed, the greater the number of connections made by the students. One approach to analyzing these results is to calculate the average percentage of concepts that students can recall individually and as a group. Further analyses can be conducted on concepts that were not mentioned or were only rarely cited, providing insight into the concepts that were not integrated into the memory engrams.

Considering that the context of applying indicators based on neuroscientific knowledge involves active learning methods and strategies, the following section introduces these approaches.

# 4 Application Scenarios

Two application scenarios are presented, each involving one of the previously introduced indicators. The first scenario relates to a module from the Machine Design course in the Mechanical Engineering program at the University of Brasília, Darcy Ribeiro Campus. This module was implemented in three different ways, on three separate occasions, each lasting three weeks with four hours of weekly classes, involving three classes and a total of 48 students.

The second scenario pertains to the Software Quality course in the Software Engineering program at the same university, but at the Gama Campus. This course was conducted twice, in different academic semesters, each lasting 15 weeks with four hours of weekly classes. It involved three classes each time, and a total of 93 students.

## 4.1 New Concept Acquisition Indicator

This indicator was used to help assess the impact of different teaching approaches and to understand whether methodological changes resulted in significant improvements in understanding and knowledge retention.

The indicator was applied in the first module of the Machine Design course, which is one of six modules, on three occasions: 2021.2, 2023.2, and 2024.1, in classes of, respectively, 14, 17, and 17 students. In 2021.2, the PBL (Problem-Based Learning) method was used; in 2023.2, the strategies of Flipped Classroom and Peer Instruction were employed; in 2024.1, both the Flipped Classroom strategy and the PBL method were used. PBL followed the approach proposed by Ribeiro (2015). The Flipped Classroom involved watching a video lecture lasting between 10 and 20 minutes before each class session and answering a digital questionnaire with 5 questions about the topic, before classroom activities. The Peer Instruction strategy was implemented as described in ELMÔR-FILHO et al. (2019).

## 4.2 Connection Network Enrichment

This indicator was implemented in the Software Quality course, part of the Software Engineering undergraduate program at the Gama Faculty, University of Brasília, over two academic semesters: the first semester of 2023.1 (with one class) and the second semester of 2023.2 (with two classes). The indicator was collected in all three classes at both the beginning (first round) and the end of the semester (second round). In the 2023.1 semester, conventional teaching methods were used with lecture-based classes and a final course project, while in the following semester, Team Based Learning (TBL) was implemented.

Using the key term "Software Quality," students were invited to list related terms that came to mind spontaneously. Subsequently, given the large number and diversity of terms mentioned by the students, categorization was carried out into four main thematic groupings: C1: Software quality characteristics; C2: Software quality assessment; C3: Software process quality; and C4: Software product quality.

Interpretations derived from this indicator can be conducted considering two perspectives: that of the discipline itself and that of the student body. When viewed through the lens of the discipline, the indicator reveals topics that require more attention and deeper exploration. On the other hand, when focusing on the students, it becomes feasible to identify which groups or specific individuals could benefit from activities exploring a yet unfamiliar theme.

# 5 Results and Discussion

## 5.1 New Concept Acquisition Indicator

To assess learning outcomes in the first module of the Machine Design course, a digital form with a list of 34 concepts—both pre-existing and acquired during the module—were utilized. Students rated their knowledge of each concept using a 5-point Likert scale to indicate the option that best represented their understanding. Only students who completed the assessment at both the beginning (Round 1) and end of the module (Round 2) were included in the analysis. As a result, the responses of 9, 13, and 10 students were counted for the academic periods of 2021.2, 2023.2, and 2024.1, respectively.

To facilitate comparisons between the strategies used, averages were calculated for all concepts in Rounds 1 and 2 for all students who completed the forms during both rounds. Bar graphs were constructed to visualize the scores for each case (Figure 1). These graphs show an expected improvement from Round 1 to Round 2. Specifically, in 2021.2 using the Problem-Based Learning (PBL) method, there was an increase of 66.5%; in 2023.2 with the Flipped Classroom and Peer Instruction approach, the increase was 63.7%; and in 2024.1 combining Flipped Classroom and PBL, the increase reached 75.2%. Notably, the combined strategy of Flipped Classroom and PBL in 2024.1 yielded the highest percentage increase. Given the limited number of students involved in these analyses, drawing conclusions about the most effective combination of strategies requires further study.

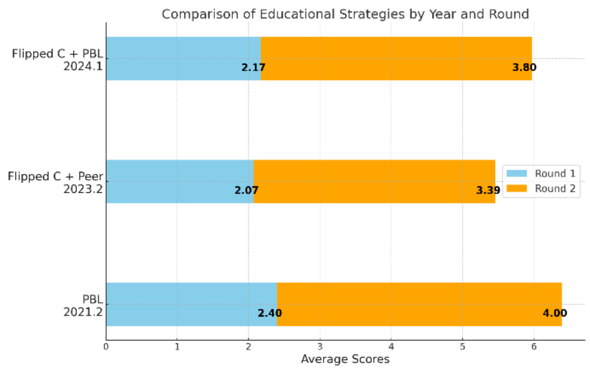


Figure 1. Comparison of educational strategies adopted in Machine Design course by year and phase

Figures 2 and 3 display the five concepts with the smallest and largest differences between the two phases for the Flipped Classroom + Peer Instruction and Flipped Classroom + PBL strategies. The results indicate that concepts with smaller differences generally represent prior knowledge, while those with larger differences are newly introduced concepts. A mean score of 4.0, achieved in several concepts, signifies full comprehension. However, the desired outcome is for students to be able to apply this knowledge effectively.

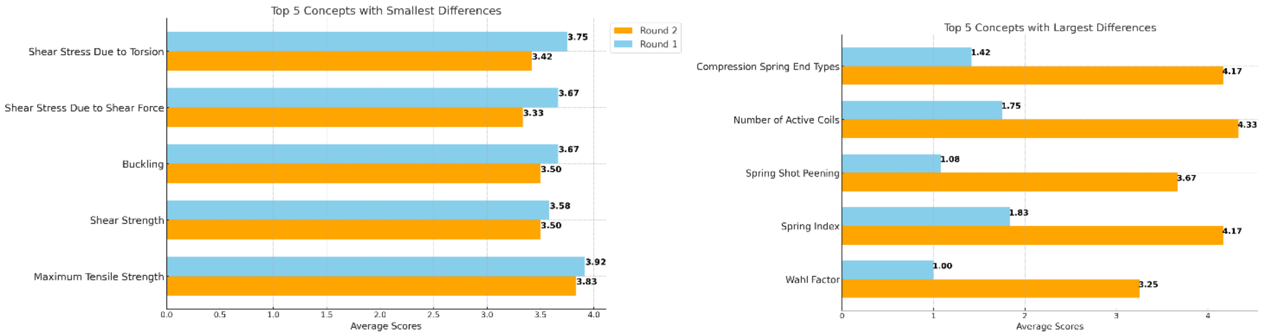


Figure 2. Concepts with top 5 (a) smallest and (b) largest differences for Flipped Classroom + Peer Instruction strategies

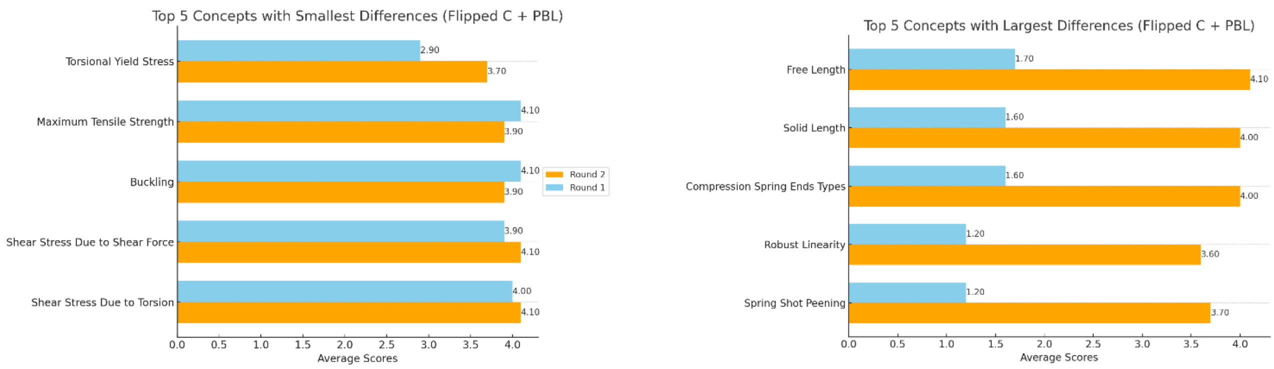


Figure 3. Concepts with top 5 (a) smallest and (b) largest differences for Flipped Classroom + PBL method

This indicator provides individual average scores for the set of concepts. Table 1 shows the percentage increase of scores from Phase 1 to Phase 2 for each student. It is noted again that an average score of 4.0 indicates that the student has a full understanding of the concept set. Shaded cells highlight that students B, C, F, G, and H require additional attention.

Table 1. Percentage increase of scores from Round 1 to Round 2 for each student in 2024.1.

| **Student** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Average of scores Round 1** | 1.78 | 2.61 | 3.00 | 1.69 | 2.36 | 2.17 | 2.19 | 2.08 | 2.14 | 1.67 |
| **Average of scores Round 2** | 4.33 | 3.72 | 3.36 | 4.00 | 4.67 | 3.61 | 2.00 | 3.36 | 4.58 | 4.36 |
| **Increase** | 144% | 43% | 12% | 136% | 98% | 67% | -9% | 61% | 114% | 162% |

It is possible to identify the concepts that received the lowest average scores, which also require attention: Deflection from Castigliano's Theorem (2.79), Bergstrasser Factor (3.14), Musical Wire (3.29), Robust Linearity (3.29), and Wahl Factor (3.29). These were the concepts least effectively assimilated by the students.

## 5.2 Connection Network Enrichment Indicator

As previously mentioned, a total of 93 students participated in the study of this indicator. In 2023.1, 33 students participated, representing 67.3% of a class of 49 students. In 2023.2, Class 1 had 23 students, corresponding to 63.9% of a total of 36 students. Class 2 consisted of 37 students, representing 78.0% of a class of 47 students.

Upon analyzing this indicator, there is a significant increase in the number of students who evoked terms in each of the categories, indicating a general trend of improvement in term recall from the first to the second round, reflecting an enrichment in the students' network of connections and an increase in information retention over the semester (Figure 4). However, terms from the category "C3: Software process quality" showed the least progress, suggesting the need for more emphasis or a different teaching strategy when addressing this topic.

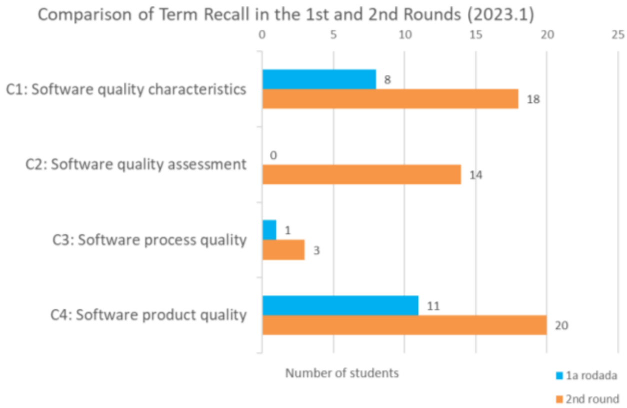


Figure 4. Connection Network Enrichment Indicator in 2023.1

In the following semester (2023.2), the Team Based Learning (TBL) method was adopted as the teaching strategy. TBL is student-centered and designed for large classes. Under the guidance of the teacher, TBL fosters interaction and collaboration in small groups (Burgess, McGregor & Mellis, 2014). The initial experiences of using TBL in the Software Engineering course at the University of Brasília began in 2017, demonstrating the feasibility of applying the method to disciplines in this area. Both students and teachers provided favorable reports on the continued use of the method (Ramos et al, 2018).

TBL follows a structured approach in three phases. It begins with the Pre-Class Preparation, where the instructor provides bibliographic material at least 15 days in advance, allowing students to prepare for the classroom activities. The second phase, Assurance of Preparation, involves taking readiness assurance tests (RAT) - first individually (iRAT - individual readiness assurance test) and then as a team (tRAT - team readiness assurance test), where students discuss and reach consensus on the correct answers. During the tRAT, the instructor provides immediate feedback. Students have the opportunity to write Appeals, challenging the instructor's answer key based on the material studied in the Pre-Class Preparation phase, fostering a deeper understanding of the theory. Finally, a mini lecture is given to clarify any doubts the students might have. In the final phase, Application of Concepts, students apply the knowledge acquired to solve problems relevant to professional practice.

Similarly to the first semester of 2023, the results from the second semester of 2023 (Figure 5) show a pattern of improvement in the recall of terms from the beginning of the semester (1st round) to the end of the semester (2nd round), particularly in the category "C2: Software quality assessment" and also in the category "C3: Software quality process". However, the categories "C1: Software quality characteristics" and "C4: Software product quality" showed no variation in Class 1, while Class 2 exhibited more significant changes.

Although more data is needed to establish a more robust measurement base, the current results suggest that the implementation of TBL may have facilitated an increase in the retention or understanding of concepts related to "C3: Software quality process," especially when comparing the classes of 2023.1 and 2023.2. The progress in categories C1 and C4, on the other hand, was more modest. This highlights the importance and usefulness of the learning indicator in identifying the topics that require greater emphasis, regardless of the teaching method adopted.

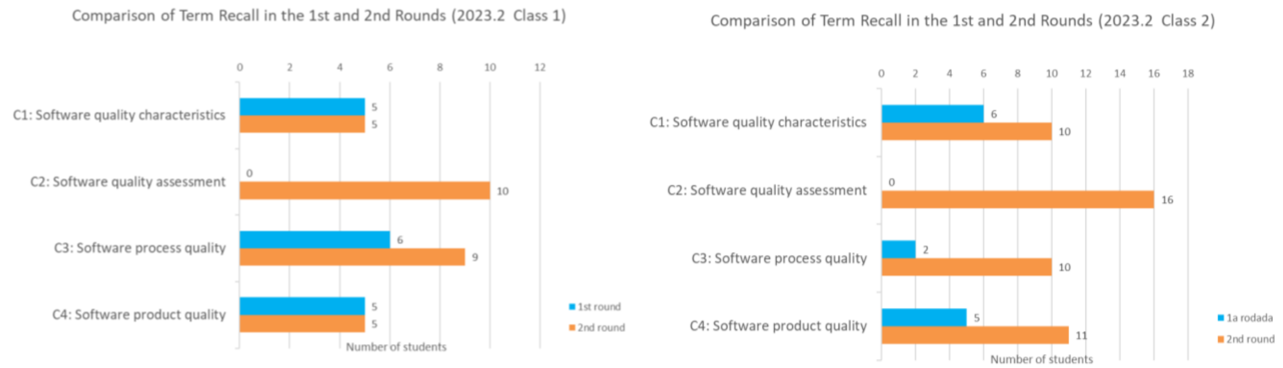


Figure 5. Connection Network Enrichment Indicator in 2023.2 (a) Class 1 and (b) Class 2

# 6 Conclusion

This study has underscored the significance of implementing learning indicators in engineering education as important tools for assessing and enhancing educational practices. Through the systematic use of indicators—specifically the New Concept Acquisition Indicator and the Connection Network Enrichment Indicator—we have demonstrated their potential in providing a detailed analysis of both student learning progress and the efficacy of instructional strategies.

The findings reveal that learning indicators facilitate a more nuanced understanding of student engagement and knowledge acquisition, enabling educators to tailor their approaches to better meet educational goals. For instance, the New Concept Acquisition Indicator highlighted areas where prior knowledge was effectively integrated with new information, leading to significant improvement in understanding complex engineering concepts. Meanwhile, the Connection Network Enrichment Indicator offered insights into the students' ability to connect new concepts with existing knowledge.

Moreover, the application of these indicators in different teaching contexts—from traditional classroom settings to innovative active learning environments like Peer Instruction, Problem-Based Learning and Team-Based Learning—has shown that they are versatile tools capable of adapting to various educational methods and contributing to a more dynamic and responsive learning atmosphere.

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# Pedagogical Architectures for the Development of Computational Thinking

Crediné Silva de Menezes[1], Rosane Aragón[1,2], Alberto Nogueira de Castro-Jr[3], Andromeda Goretti de Menezes Campos[4]

[1] Interdisciplinary Center of New Technologies in Education, Federal University of Rio Grande do Sul, Brazil
[2] Faculty of Education, Federal University of Rio Grande do Sul, Brazil
[3] Institute of Computing, Federal University of Amazonas, Brazil
[4]Federal Institute of Education, Science, and Technology of Espírito Santo, Brazil

Email: credine@gmail.com, rosane.aragon@gmail.com, alberto@icomp.ufam.edu.br, andromeda.campos@ifes.edu.br

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**Abstract**

Computational thinking is internationally recognized as an essential tool for solving problems in several areas of knowledge, and its inclusion in all levels of education is widely advocated. Although many initiatives have been undertaken in basic education, the discussion about applying computational thinking in higher education is still incipient. In order to enhance debate on the subject, we held an Advanced Seminar for students of an Informatics Applied to Education Doctoral Program, exploring the creation of Pedagogical Architectures (PA) that incorporate computational thinking into learning activities. Pedagogical architectures are understood as a pedagogical approach based on the articulations between constructivist theory, Paulo Freire's pedagogy, and the perspective of a Learning Ecology. These architectures involve mobile and reconfigurable articulations between open pedagogies, technologies, and organization of time and space, offering support to individual and collective learning processes. At the end of the seminar, the concept of a PA that fosters computational thinking in students of different levels of education and areas of knowledge was proposed to the participants, organized in groups. Subsequently, a peer review was carried out, in which each individual analyzed a proposal of another group. Conceptual reconstructions occurred in alternating individual and collective moments of action-reflection, seeking necessary consensus for developing PA proposals. Analysis of this Seminar endorses an aptitude of Pedagogical Architectures for promoting computational thinking in students. Each pedagogical architecture's ability to encourage computational thinking in students was analyzed, and results evidenced favorable and assorted scenarios for it.

**Keywords**: Computational Thinking; Pedagogical Architectures; Constructivism.

## 1 Introduction

Critical thinking training has been neglected at all levels of the educational system globally. Upon entering higher education, teachers perceive that previous school levels are not adequately preparing students for professional formation. Similarly, employers notice this unpreparedness in their new hires (ISTE, 2023).

In various countries worldwide, efforts are being made to reintroduce initiatives that ensure a more solid education in this fundamental aspect for personal development, life in general, and the world of work. Additionally, as this type of thinking is crucial in life and even for the learning process, supporting this development is essential in preparing citizens with an education more compatible with the competency demands inherent in problems in the modern world.

With the increasing availability of digital technologies, opportunities arise to tackle problems whose solutions can significantly alter our living experience in an increasingly complex world. We can include learning processes among our problems.

In this scenario, a new approach emerged in the first decade of the millennium to address problems: the exercise of computational thinking, which is increasingly seen as the gateway to reintegrating critical thinking into our problem-solving process.

In this article, we present an experiment on the design of new teaching proposals aimed at integrating interdisciplinary problem-solving practice, supported by digital technologies and underpinned by principles and strategies that can be applied universally across all fields of academic and professional knowledge. Resulting artifacts, devised as pedagogical architectures by the participants, were analyzed with respect to pedagogical and computational thinking rationale.

The article is organized into five sections. After this introduction, we present the theoretical framework supporting the conception and analysis of new approaches to the development of computational thinking, which are discussed in the following sections. In Section 3, we present a teaching experiment using Pedagogical Architectures to develop Computational Thinking. In Section 4, we analyze student productions, and in Section 5, we show the final considerations about the experiment.

# 2 Theoretical Framework

This section presents some concepts needed to support the design and analysis of Pedagogical Architectures for developing Computational Thinking.

## 2.1 Computational thinking

Education, at all levels, aims to prepare citizens to a) solve problems relevant to the well-being of humanity, b) critically analyze situations to enable decision-making, and c) acquire new concepts. It is not only about applying known models to similar situations; it is necessary to develop the ability to find new solutions to problems, using resources that contribute to social or economic gains and thus finding solutions to new problems (Sternberg, 1986; Piaget, 1972).

The pursuit of systematizing an education that favors the preparation of human beings to achieve the objectives mentioned above is quite ancient and has become known as "critical thinking." This pursuit dates back to antiquity with founders such as Plato and Aristotle. In modern times, John Dewey (1933) is considered to have assumed this role. According to recent studies (Kules, 2016), the concern for developing critical thinking has gradually been set aside in the educational process, which has been a cause for concern in many countries.

Running parallel to initiatives to reintegrate critical thinking into the educational context (Sternberg, 1986; Kules, 2016), we saw the emergence in 2006 of a related concept called Computational Thinking (Wing, 2006), which has mobilized numerous institutions around the world to integrate Computational Thinking into the educational system at all levels. The current literature is extensive, both by enthusiasts and critics. The text presented by Wing (2006) profoundly impacted academic minds worldwide. As a result of these initiatives, we can find resources ranging from pedagogical resources to proposals for integrating computational thinking into the curriculum.

While Computational Thinking has been interpreted by many as a set of strategies to support problem-solving in any area of human knowledge, others have interpreted it as the creation of systems whose outcome is the development of algorithms that human and not human agents can execute. It is usual to see an emphasis on learning to program in different programming languages, many of which are 'block'-based. We find important computational thinking strategies in the specialized literature known as its "pillars." The following stand out: Abstraction, Decomposition, Pattern Recognition, and Algorithms (Rao, Bhagat; 2024). The Abstraction pillar refers to the strategy of considering only the essential characteristics of objects; Decomposition consists of identifying simpler sub-problems that facilitate the resolution of the main problem; Pattern Recognition refers to the identification of relevant patterns or trends to understand the problem, and finally, Algorithms refer to establishing a sequence of steps to achieve a particular end.

Although criticisms can be found regarding this reduction of studies on the development of critical thinking (Easterbrooks, 2014), we can understand that the success of initiatives supported by them, and some others more cited, favor the resumption of a tradition of training people to use problem-solving strategies.

## 2.2 Pedagogical Architectures

Digital technologies have aroused the interest of researchers, teachers, and the general public in supporting the production of digital materials and social communication. Forty years after the emergence of computers, the Internet has reached many people worldwide. Throughout the same period, research in Artificial Intelligence explored various methodologies, resulting in significant advancements that are currently applicable in the educational field. At the dawn of the new millennium, the Internet began to be accessed from mobile devices. Along with these technological innovations, many others emerged. All these contributions were noticed by those interested in the production and dissemination of content, as well as in the creation of environments to foster social interactions.

Many initiatives to promote education emerged—first, the so-called educational software, followed by learning objects and learning management systems. However, the use of these tools in the school context continued with low integration into the daily life of the classroom.

More recently, a movement initiated in the late 19th century, Ferriere's New School, characterized by the student's active participation in their learning process, has returned to the agenda, this time labeled as active methodologies. This return is mainly due to the possibilities provided by new media for the production of interactive objects, digital communication mechanisms, and the advent of mobile Internet and smartphones (Hartikainen et al., 2019).

However, it is not enough one's desire to adopt the concept of active methodologies in school practice; a methodological approach that favors the engagement of teachers and students in new practices is necessary. Therefore, it is essential to have theoretical foundations that provide the necessary support for adopting active methodologies. Today, we can find several examples of active methodologies in the academic literature that are not always supported by digital technologies and appropriate theoretical frameworks (Hartikainen et al., 2019).

As learning situations vary and solutions depend on the content's nature and the classroom context's specifics, more is needed than a repertoire of methodologies. The teacher cannot be satisfied with being a mere implementer of practices proposed by others that do not always fit their specific situation. In addition to a good repertoire, it is essential to be given the freedom to create.

With this intention, the Pedagogical Architectures framework was conceived, a theoretical-methodological support for designing new active methodologies anchored in Jean Piaget's constructivism (Piaget, 1968) and Paulo Freire's Pedagogy of Questioning. The proposal is also based on a new conception of time and space, adoption of the Internet as an actual development platform, Virtual Learning Environments, and Artificial Intelligence Tools (Carvalho, Aragón, Menezes, 2005; Aragón, 2016; Menezes & Aragón, 2018; Menezes et al. 2021). The conception of Pedagogical Architectures considers the following pedagogical principles:

1. Educating towards the search for solutions to real (everyday) problems;
2. Educating so that individuals are able to transform information into knowledge;
3. Educating to encourage authorship, interlocution, and the use of different languages;
4. Educating to build autonomy and cooperation;
5. Educating to promote investigating and reflective subjects.

Some elements can be highlighted for a better understanding of this framework:

- Piaget's constructivism ensures that the teacher's role is not that of someone who gives lectures but rather someone who offers work proposals to the students, problematizes, and provides support for the advancement of students in their quest for knowledge construction (Becker, 2001);
- Educational activities aim to explore the objects of study by the students, sometimes individually, sometimes in cooperation, always supported by their prior knowledge, which will enable them to anchor new knowledge;
- The materials to be explored, as well as the problems to be solved, should be based on the student's interests, preferably supported by their demands;
- There is no need for activities to be carried out only in the classroom space or at a specific time. The use of the Internet offers the possibility of asynchronous cooperation. Everyone's work, whenever possible and desirable, can be carried out from different places. Materials, authoring environments, and student productions might be hosted in 'the cloud' so that everyone (teacher and students) can access them from anywhere (provided they have internet access);
- Tedious or mostly operational activities, low on intellectual work, both for the teacher and the students, can be carried out with the support of artificial intelligence and other support software;
- Intellectual activities should always aim to develop thinking triggered by the cognitive imbalances needed to lead students to reach new equilibrium levels.

### 2.3 Pedagogical Architectures and the development of the Computational Thinking

Computational Thinking is not a simple content that should be taught but rather a problem-solving competency that individuals need to develop. This competency is based on a repertoire of strategies (pillars) that can be used to seek solutions to a problem. Furthermore, it constitutes an interdisciplinary skill.

We understand that a Pedagogical Architecture should always provide opportunities for students to develop computational thinking. The student's development will come from seeking the appropriate strategy to solve a given situation at each point.

## 3 A Teaching Experiment

To carry out an in-depth study of the relationship between Pedagogical Architectures and the development of computational thinking, we planned and conducted an Advanced Seminar titled "Pedagogical Architectures for Computational Thinking Development." That 60-hour seminar was distributed over weekly sessions of 4 hours each. Participants were all PhD students from the Informatics in Education Graduate Program at the Federal University of Rio Grande do Sul, in Brazil. Five of them are men and two are women, aged between 25 to 45 years old with no previous knowledge about the seminar contents. The seminar was developed based on Pedagogical Architectures. The conceptual appropriation was based on the Pedagogical Architecture of "Cooperative Reading," (Müller et al, 2021) which involved reading and summarizing articles, followed by a peer review of the document produced by participants from previous readings. The summaries and reviews were recorded in a virtual learning environment. After each cooperative reading, sessions were held to debate individual positions on the content of the readings.

Following the reading of foundational texts on Pedagogical Architectures and Computational Thinking, an activity was conducted to analyze two Pedagogical Architectures to investigate whether there was evidence of their potential to support the development of Computational Thinking. Two Pedagogical Architectures, "Learning Projects" and "Thesis Debate" (Menezes, Castro-Jr, Aragón, 2021) were analyzed. In this assessment, students identified pedagogical principles as the basis for the Pedagogical Architectures and attributed a high potential for these architectures for the development of Computational Thinking. After completing this activity, debates were held to share the participants' perceptions within the teams.

Subsequently, two teams were formed, with a different composition from the first ones. The teams were asked to design Pedagogical Architectures aimed at developing Computational Thinking in school contexts. Each team had the autonomy to choose the target audience and the architecture theme. The proposals were documented and made available for reading and analysis by each participant in the class. The participants from each team read and provided documented feedback on the other group's proposal.

This activity ran concurrently with new cooperative reading activities, addressing advanced aspects of Pedagogical Architectures and Computational Thinking. At the end of the activities, each participant produced an individual report reflecting on their learnings derived from the readings and activities involving analyzing known architectures and producing new architectures.

# 4 Analysis Results

The analysis was conducted to elucidate *whether or not* and *how* the two groups of students in the seminar utilized the theoretical foundations and possibilities for developing Computational Thinking (CT) in the architectures created. During the seminar, before elaborating a pedagogical architecture proposal, students evaluated existing architectures such as "Learning Projects" and "Thesis Debate". In that evaluation, students identified pedagogical principles serving as the basis for the Pedagogical Architectures (PAs) and attributed a high potential of these architectures for CT.

The data evaluated consisted of writings produced by the two groups, with references to activities at each stage of the pedagogical architectures. Firstly, each stage was analyzed to gather evidence of the relationship between those activities and their rationale. After this analysis, the pedagogical architectures were evaluated as a whole, aiming at identifying which pedagogical principles and CT pillars were considered/valued when designing proposals. For the analysis of the architectures developed by the students, two categories were defined as follows:

**Category 1** - Pedagogical Principles: Use of the "Constructivism" and "Freirean Theory" learning theories in the student group's PA proposal. Drawing upon the work of Carvalho, Nevado, and Menezes (2005), we considered the articulations between constructivism and Freirean theory, synthesized into five pedagogical principles, as previously presented in Section 2.2.

**Category 2** - CT Pillars: Use of the four Pillars of Computational Thinking that are evident in different stages of the architecture. Each stage may emphasize certain pillars, depending on the proposed action. The pillars considered are (a) Abstraction, (b) Decomposition, (c) Pattern Recognition, and (d) Algorithm, as presented in Section 2.1.

The following are the analyses of the pedagogical architectures devised by the two groups. After a brief description of each one, a table summarizes found relationships between pedagogical principles and CT pillars (categories 1 and 2). Relationships are grouped according to action developed at a certain stage of each PA.

## 4.1 Analysis of the Pedagogical Architecture Proposed by Group 1

**Title**: Problem Solving for the UNESCO BR Sustainable Development Goals (SDG) List

**General Description of the Proposed PA**: The PA proposed by Group 1 involves working with students in the final grades of Elementary School on the United Nations Sustainable Development Goals (SDGs) to construct solutions for problems. The proposal can be adapted according to a teacher's intentions and the specifics of each class for application in other educational stages.

**Pedagogical Principles Considered in Various Stages of the Architecture**: The proposed architecture starts from the central idea of the need for interaction with the objects of study and among students, which is addressed from the early stages, as illustrated in stages 1, 2, and 3, where students participate in choosing one of the UN SDGs to be worked on in the PA. Real problem-solving, experienced by the students, begins in Stage 1 when the study object (SDGs) is defined.

The principle that predominated in the organization of the PA was "educating to promote autonomy and cooperation" (principle 4), showing recognition of the importance of cooperative learning for students' knowledge advancement. Also, "educating to encourage authorship, interlocution, and the use of different languages" was presented significantly. The principle of "educating to promote inquiry-minded and reflective individuals" is explicit in the final stages, indicating that the student authors of the PA conceive it based on cooperative learning, authorship, and dialogue.

**Aspects of CT Pillars Privileged in Various Stages of the Architecture**: Aspects of CT Pillars Privileged in Various Stages of the Architecture: The student authors of the PA considered that the proposal involves all four pillars of CT, with an emphasis on abstraction. The organization of tasks considered, the need for pattern recognition for problem formulation, data collection, and analysis. The demand for decomposition skills and algorithm usage arises explicitly from the stage of constituting an interdisciplinary approach to problem-solving.

Table 1. Summarizes the relationships the group of student authors established between the stages of the proposed pedagogical architecture, the considered pedagogical principles, and the CT postulates.

Table 1. Survey of relationships established between the stages, pedagogical principles, and CT pillars.

| **Stages** | **Action** | **Pedagogical Principles** | **CT Pillars** |
|---|---|---|---|
| **Stage 1** | Choice of one of the UN SDGs | (1) solutions to real (everyday) problems<br>(4) development of autonomy and cooperation | Abstraction<br>Pattern recognition |
| **Stage 2** | Selection of topics to be addressed | (1) solutions to real (everyday) problems<br>(4) development of autonomy and cooperation | Abstraction<br>Pattern recognition |
| **Stage 3** | Group formation | (4) development of autonomy and cooperation | Pattern recognition<br>Algorithm |
| **Stage 4** | Interdisciplinary approach | (2) to transform information into knowledge<br>(3) authorship, interlocution, and the use of different languages | Abstraction<br>Pattern Recognition<br>Decomposition<br>Algorithm |
| **Stage 5** | Inter-group dialogue | (3) authorship, interlocution, and the use of different languages<br>(4) development of autonomy and cooperation | Abstraction<br>Pattern Recognition<br>Decomposition<br>Algorithm |
| **Stage 6** | Analysis, discussion, and peer critique | (4) the development of autonomy and cooperation<br>(5) to promote investigating and reflective subjects | Abstraction<br>Pattern Recognition<br>Decomposition<br>Algorithm |
| **Stage 7** | Final work development | (3) authorship, interlocution, and the use of different languages<br>(4) development of autonomy and cooperation<br>(5) to promote investigating and reflective subjects | Abstraction<br>Pattern Recognition<br>Decomposition<br>Algorithm |
| **Stage 8** | Presentation of developed works | (3) authorship, interlocution, and the use of different languages<br>(4) development of autonomy and cooperation<br>(5) to promote investigating and reflective subjects | Abstraction<br>Pattern recognition |

## 4.2 Analysis of the Pedagogical Architecture proposed by Group 2

**Title**: Problem-Solving using Educational Robotics Elements

**General Description of the Proposed PA**: This pedagogical architecture uses educational robotics to foster and develop computational thinking in students, emphasizing teamwork and knowledge construction through investigation and real problem-solving.

**Pedagogical Principles Considered in Various Stages of the Architecture**: Similar to PA1, the central idea of interacting with study objects and addressing real problems is emphasized from the early stages, where students interact with various sources of information and define a problem to be addressed in the PA. The main principle considered by students in architecture involved "educating to promote inquiry-minded and reflective individuals," aligning with the broader objectives of PAs. They also prominently identified the principle of "educating to encourage authorship, interlocution, and the use of different languages," followed by the postulate on autonomy and cooperation. The organization of the PA allows us to observe that students have incorporated all five pedagogical principles into their proposal, indicating an understanding of these principles that have been translated into various stages of the PA.

**Aspects of CT Pillars in Various Stages of the Architecture**: The student authors of the PA considered that the proposal involves abstraction, task organization into smaller parts, pattern recognition, and algorithm usage in most stages. According to the student authors, the students to whom the PA will be applied (targeted for an age range of 13-14 years) will enhance their teamwork, reflection, and analysis skills, which will undoubtedly propel knowledge construction. Only algorithm usage skills are not included in the stages of problem definition, analysis of works, and evaluation of the results of the proposed PA.

Table 2. Survey of relationships established between the stages, pedagogical principles, and CT pillars for PA2.

| Stages | Action | Pedagogical Principles | CT Pillars |
|---|---|---|---|
| **Stage 1** | Students research a topic of interest and develop a problem to be solved. | (1) solutions to real (everyday) problems<br>(5) to promote investigating and reflective subjects | Abstraction<br>Pattern Recognition<br>Decomposition |
| **Stage 2** | Reflecting on the problem situation at hand, identifying and planning its solution. | (3) authorship, interlocution, and the use of different languages<br>(5) to promote investigating and reflective subjects | Abstraction<br>Pattern Recognition<br>Decomposition<br>Algorithm |
| **Stage 3** | Execution of actions. | (2) to transform information into knowledge<br>(3) authorship, interlocution, and the use of different languages<br>(4) development of autonomy and cooperation<br>(5) to promote investigating and reflective subjects | Abstraction<br>Pattern Recognition<br>Decomposition<br>Algorithm |
| **Stage 4** | Verification/validation of the solution. | (3) authorship, interlocution, and the use of different languages<br>(5) to promote investigating and reflective subjects | Abstraction<br>Pattern Recognition<br>Decomposition<br>Algorithm |
| **Stage 5** | Visiting and analyzing the productions of other groups. | (3) authorship, interlocution, and the use of different languages<br>(4) development of autonomy and cooperation<br>(5) to promote investigating and reflective subjects | Abstraction<br>Pattern recognition<br>Decomposition |
| **Stage 6** | Construction of the final prototype. | (2) to transform information into knowledge<br>(3) authorship, interlocution, and the use of different languages | Abstraction<br>Pattern recognition<br>Decomposition<br>Algorithm |
| **Stage 7** | Participatory evaluation. | (5) to promote investigating and reflective subjects | Abstraction<br>Pattern recognition |
| **Stage 8** | Presentation of the product, considering the evaluation conducted in the previous stage. | (4) development of autonomy and cooperation<br>(5) to promote investigating and reflective subjects | Abstraction<br>Pattern recognition<br>Decomposition |

## 5 Concluding Remarks

The two architectures proposed by the students allowed us to identify, albeit with different emphases, the presence of all five principles that support them theoretically and pedagogically. The stages that make up the architectures, as a whole, showed that the students were able to transform these principles into authorial pedagogical practices, which presented different possibilities for configuring a PA. The focus of the proposed PAs can illustrate these differences. While PA1 emphasizes the principle of educating for the construction of autonomy and cooperation, PA2 appears more supported by the idea of forming inquiry-minded and reflective individuals. However, although these PAs presented some differences regarding a greater focus on some of the principles, this does not constitute dissonances but rather variations since the pedagogical principles encompass the same idea of promoting knowledge construction. It can also be emphasized that the PAs were elaborated to consider an ecological perspective of learning, in which the pedagogical principles, practices, resources, times, and learning spaces are interrelated components forming a "framework" or structuring support for cognitive constructions.

From the standpoint of the four pillars of Computational Thinking, we can observe that they are present in all stages of the proposed architectures. We highlight that the Abstraction pillar appears in almost all stages of the two architectures. This finding is consistent with the importance of abstraction in all activities we undertake. Next comes the Decomposition pillar, which is also compatible with its role in problem-solving, identifying sub-problems that facilitate various aspects of a solution. Lastly, the Algorithm pillar appears to have a precise role in determining steps to organize the flow of tasks and generally appears in the final stage of developing a solution.

Although our observations were limited to a specific context (teachers devising new pedagogical proposals), the analysis results are promising, as participants have been able to appropriate the seminar contents and demonstrate their willingness to use the Pedagogical Architectures Framework as a conceptual tool in designing embodying CT aspects. Future work on design of teaching proposals based upon pedagogical architectures and computational thinking, might include groups from other knowledge areas and education levels. Further work should also focus on solutions for specific and complex issues like students with special educational needs or sustainable solutions for small communities.

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# Makerspace in Poverty Communities: Maker Culture and its Impact on the New Generation

Frederico Pifano de Rezende[1, 2], Afsaneh Hamedi d'Escoffier[3], Taciana Gatto[4]

[1] Instituto Federal do Espírito Santo, Espírito Santo, Brazil
[2] Texas A&M University, College Station, TX, USA
[3] Lab. Protozoologia, Instituto Oswaldo Cruz, Fundação Oswaldo Cruz, Rio de Janeiro, Brazil
[4] Secretaria de Educação do Estado do, Rio de Janeiro, Brazil

Email: fredpifano@gmail.com, afsanehamedi@gmail.com, taianagatto@gmail.com

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**Abstract**

The present proposal has the objective to be a "culture developer" and develop the current stage of potential technical and technology and the meeting of knowledge between IFES-Cariacica high school students and young people enrolled in fundamental schools of this municipality to project a creative insertion in the contemporary world of work. As specific structured objectives, in addition to a literature review on the relationship between technique, technology, knowledge, and bioethics in the 21st century, develop work with students who graduated in Production Engineering and Management Technicians to disseminate Maker Culture in public schools. Municipalities of the Cariacica city; Present the possibilities of 3D Printing for students and teachers, besides the concrete exercise of its use; and transform IFES Cariacica Makerspace into a training space for a new mindset for children and youth impacting the learning culture. Participatory research was carried out in 14 municipal schools in Cariacica, involving a total audience of 601 people. Lectures and workshops were held using computers and 3D printers, where participants accessed existing technologies at the institution to learn about, produce, and demonstrate viable future processes for work experiences. The activities will be conducted by students from the Integrated Technical Management Course and the Production Engineering Bachelor course at the IFES Cariacica campus. The results will be obtained through groups focused on the research subjects after workshops, where they will be allowed to capture as possible transformers that occurred after the project. Throughout the project, IFES Cariacica Maker Space will be open to municipal schools, creating a reference place, among others, for rapid protection and 3D printing.

**Keywords**: Makerspaces; Engineering Education; Maker; 3D printing.

## 1 Framework

Cupani (2011), while discussing the complex and ambiguous relationship between reflection and action, manifested both in technique and technology, asserts that: "What seems to unite ancient and modern forms of technology (...) is the circumstance that they represent manifestations of the human capacity to make things. Also, all production, technical or technological, manifests knowledge. The capacity to make things means the capacity to produce the difference from the capacity to act, that is, to lead one's own life (instead of living purely instinctively). By making, man originates artifacts, artificial objects or processes".

Engineering presents itself as a historical process that demarcates, in various times and spaces, the creative, projecting, and open to the new production inherent to the human condition. In this sense, for those of us who, as teachers, technology presents itself as an open field for reflection, whether on its use or appropriation, but essentially on the human values behind the said phase of social production of life. Technology is a daily presence in teaching through the devices available in consumer society. Still, it only presents itself as a potential for dreams in the student universe if linked to the perspective of teaching and work.

As educators, we know that there is no education without reflection and that anxieties are overcome as changes in scenarios within the field of work open their horizons to the new and renew the daily routine of educational action based on new or renewed experiences socialized in various parts of the world. Action in teaching is linked to continuous concern about students' future and the instruments available to provide a creative, innovative, and student-centered education. In this sense, the sciences of technology and philosophy intersect as thinking about life and materializing new material/sensory meanings for present and future generations becomes a point of reference in constant movement from what is understood by education in general and institutionalized education in particular.

According to the *"Anuário Brasileiro da Educação Básica,"* 2018, of the almost 49 million people inserted in this educational scope, nearly 40 million are in the public education system. Within this, there are approximately 6 million in early childhood education, 23 million in elementary education, 7 million in high school, 3 million in Youth and Adult Education, 1 million in vocational education, and 46 thousand in unique/specialized schools. These numbers call us to think about this majority universe of young people enrolled in elementary education who will not necessarily present themselves as potential students in the Brazilian public high school. The Federal Institute of Education IFES, with its techniques, technologies, and knowledge, is a national power that materializes this insertion as a future space for the work life of a significant part of the 23 million people enrolled in the Basic Education network.

Also, according to the Yearbook (2018), regarding the Socioeconomic Level (SES), those in conditions ranging from very low to medium within the public network correspond to more than 16 million people, a predominantly young audience. This allows us to reflect on the era of access in consumption, but not necessarily in conscious use to produce always open creative possibilities. It is from this ambiguous coexistence between the most advanced technological era and the multiple facets of despair that haunt youth that we understand the centrality of the role of IFES in society and of the techniques and technologies it possesses and should be available to this group so that their dream universes can be re-signified.

In this sense, the present proposal, covered by documented reflections from the science, technology, and society field, has as its territory a concrete realization of the experience of IFES-Cariacica's action with the public municipal schools of this same municipality. Our 15-year tenure as faculty in the Engineering and Administration courses and fieldwork experiences have required deep reflection on the redefinition of education in the 21st century from the field of bioethics. In the words of Mitcham (1994, cited by Cupani 2011): "The humanities, or philosophy, which could also be called the hermeneutics of technology, seek, by contrast, an understanding of the meaning of technology - its relationship with the trans-technical: art and literature, ethics and politics; religion. It typically begins with non-technical aspects of the human world and considers how technology can (or cannot) adapt or correspond to them" (p. 27).

From this relationship between education committed to the territory and the potential advancement of access to technique as knowledge available to society, these fields merge in the experience of IFES-Cariacica, in general, and the Engineering and Administration courses, in particular. Over the past 13 years, the Federal Institute of Education IFES, Cariacica Campus, has stood out in offering education and preparation for the world of work to the city's residents and its surroundings in the Greater Vitória region.

Considering concrete action in the territory, this research also aims to elucidate the relevance of this category - territory - in light of the teachings of Milton Santos, one of the excellent references in the debate on the space-time technique from a humanistic perspective of geography. For Santos & Becker (2007): "territory is not only the set of superimposed systems of things; territory must be understood as territory used, not the territory itself. The used territory is the ground plus identity. Identity is the feeling of belonging to what belongs to us. The territory is the foundation of work; the place of resistance, material and spiritual exchanges, the exercise of life" (p. 23).

In approaching its context, IFES-Cariacica regularly carries out a project called "Open Doors," where municipal schools from Cariacica visit the IFES facilities to uncover study possibilities and the selection process. Over the past four years, it was possible to perceive that many students from these schools did not register for the selection process because a "complex of inferiority" was part of the culture of the municipality's students. Opinions such as:

- "I am not good enough to study at IFES";
- "Only those who can afford the preparatory course enter IFES";
- "IFES is a very distant dream";
- "Those who study at IFES must be happier."

As part of the work of the responsible team, students were encouraged to register for the selection process during the visit, and the accompanying teachers began to guide the registrations. The already perceived result is that students who participated in the "Open Doors" project are gradually becoming students at IFES on various Campuses. As proof of the importance of dissemination and approach to IFES society, we have the fact that in the current academic year, 2023-2024, the residents of Cariacica represent 47.85% of the campus students. The project in question was not the only factor but made a significant contribution. From it, the need for greater interaction with the schools of Cariacica was also noticed.

Another project on campus, as an activity of the Administration course, in partnership with Junior Achievement, is the Mini-Company Project. This project, which encourages the formation of an entrepreneurial culture, has been demonstrating over the past four years that students who make up the so-called "Generation Z" respond well to the calls of Do It Yourself (DIY) proposals, which is a determining component of the Maker Culture, which in turn is derived from accessibility to rapid manufacturing and prototyping machines that drive the so-called "Industry 4.0".

From these two experiences, it was possible to observe that the students of Cariacica admire the IFES Institution. However, their belief that accessing it is difficult prevents them from daring to try. Students who enter IFES prefer practical activities as a form of learning.

Our intention, over the four years we will have to study and reflect on the ambiguities and potentialities of the theme, is part of these two inseparable scopes: a) future public of IFES from the presentation, with the protagonist of high school and undergraduate students, of the courses and projects we have; b) in the action of high school and undergraduate education and their relationships with society - Cariacica - the provision of techniques and technologies that open horizons of meaning to youth about their future work environment.

In the scope of the IFES-Community relationship in Cariacica, we understand that the use and provision of technology (Additive Manufacturing) can be an excellent reflective exercise on the conditions of creativity and ingenuity of the region's youth. Socializing access and democratizing knowledge and skills that often only inhabit the imagination of children and adolescents become one of the premises to be reflected and deepened in the study over the following years of postgraduate education.

In this sense, as a basis for understanding, we can comprehend that digital manufacturing, once restricted only to companies and large product developers, has evolved widely thanks to technological advances that could be perceived at various distinct stages and sometimes concomitant over time. Evolution in software and hardware brought more powerful and accessible computers to the public; simultaneously, in telecommunications, the internet was born, and with it came the digital revolution in manufacturing, where access to information was facilitated, and thus, the public began to be able to design their products and produce them (Gershenfeld, 2007).

Termed "digital manufacturing," this new production method makes the end user more active in the production process. They build precisely what they need without the intermediary of any company, and waiting for delivery is often long and frustrating (Igoe & Mota, 2011).

An intrinsic practice to digital manufacturing is Do It Yourself (DIY)." This expression refers to entrepreneurial, creative, and innovative behaviors that have the potential to develop and improve people's learning abilities. It is believed that when this practice is encouraged in an environment with tools that enable prototyping, significant progress, and innovations can be obtained in how products are created and developed (Eychenne & Neves, 2013).

Laboratories that provide digital manufacturing began to appear in the early 2000s, and the most emblematic and well-structured one was the Fabrication Laboratory or Fab Lab. One of the several names given to environments with this purpose is Maker Space, where users are encouraged to create various types of products through their development in a virtual environment through specific software and subsequently their production, either by 3D printing, milling, cutting, or whatever equipment is available in that environment (Gershenfeld, 2007).

DIY practices are closely linked to Makerspaces since enthusiasts find everything they need to develop their projects in these laboratories. Another attractive factor to this audience is that these places, among other characteristics, are zero-cost or affordable to their users (Gershenfeld, 2007).

Roslund and Rodgers (2014) define makerspaces as places where people gather to produce things. These spaces can focus on electronics, robotics, woodworking, laser cutting, programming, or a combination of these activities.

One of the most significant advantages and attractions of digital manufacturing laboratories and maker spaces is that people can imagine a product and have it in their hands moments later. Even if they are not experts in prototyping, the technical staff available in the laboratories can assist less experienced users in their projects (Troxler, 2010).

Exploring this resource type in an educational environment opens broad possibilities for innovation in student learning processes. Education, in general, long stagnated by passive methodologies, can take advantage of these new tools, allowing students to create prototypes to solve real problems. This is revolutionary in learning, research, and technological innovation.

For students to be able to deal with new technologies considering social, ethical, environmental, and economic aspects, the teaching staff of their educational institution must be adequately prepared to stimulate their skills through a methodology that accompanies these new global trends. For all this to be possible, schools must commit to providing physical structure so that the entire learning process is effective (Masson et al., 2012).

Project-Based Learning (PBL) provides integral and gradual learning through practice and continuous challenges. Its development originated in the 1900s with the philosopher John Dewey, who proved it through his students by "learning by doing," valuing them, contextualizing them, and questioning them progressively to solve real problems in projects related to the contents of the study areas, where experimental activities were fundamental (Ribeiro & Mizukami, 2004).

The essence of the Maker Space is closely linked to PBL, as both seek the construction of knowledge through interactions with the environment and proposed challenges, stimulating creativity and problem-solving skills. This idea is also reflected in constructivism, which explains how individuals build and develop knowledge through investigations, activities, dynamics, and interactions with the resources around them. Constructivist theories argue that knowledge does not exist absolutely, but the progress made through global perception, integration of knowledge, and relationship with the environment can bring new possibilities to students (Markham et al., 2008).

PBL has been one of the leading centers of discussion in approaching more active learning and innovative teaching practices. Considered an alternative learning of the current century, it demands more dedication from teachers and students to be efficient. Teachers must change their traditional role as experts in a subject to learning coaches. Similarly, students must exert more effort and understand that knowledge will only be obtained through dedication (Campos, 2011).

Another relevant aspect related to Maker Spaces and active learning methodologies is the acronym STEM (Science, Technology, Engineering, and Math). These learning spaces have substantially supported the formation of a new mindset in students, generating interest and curiosity that allow a greater connection with science, technology, engineering, and mathematics. Martinez and Stager (2013) point out that this educational perspective will become decisive for economic progress, and these skills will be fundamental in global competitiveness.

For the "academy" to modify the traditional teaching model and improve it for a new reality that follows new global and technological trends, it is necessary to invest in laboratories adequately equipped for such feats. Maker Spaces brings this reality to educational institutions in an innovative and accessible way.

## 2 Research objectives

The primary purpose of this work is to elucidate how the "maker culture" and the current stage of technique and technology enhance the exchange of knowledge among high school students in Administration and undergraduate Engineering students at IFES-Cariacica and young people enrolled in schools in this municipality, aiming to concretely project a creative insertion into the contemporary world of work. To achieve this, the following objectives are intended:

- Study the reality of the region to which IFES-Cariacica belongs, considering an actual study on youth, their level of education, and school dropout rates, using the methodology of focus groups linked to PBL.
- Develop a project with students, administration technicians, and undergraduate Engineering students to disseminate the Maker Culture in public municipal schools in Cariacica.
- Present the possibilities of 3D printing to students and teachers, in addition to the practical exercise of its use.
- Foster a future perspective for young Engineering, Science, Technology, and Mathematics students.
- Transform the Maker Space at IFES-Cariacica into a center for shaping a new mindset for the child and adolescent audience, impacting the learning culture.

## 3 Methodology

The main aim of this work has been to determine to what extent the maker culture associated with PBL methodology and contemporary techniques and technologies available at IFES-Cariacica allow us to redefine the role of education in the territory as a meeting of knowledge in the service of providing accurate and creative opportunities for youth in their future integration into the world of work.

Conceived to carry out interventions in the institutions that will serve as the research field, this project initially assumed qualitative characteristics regarding its nature and exploratory in terms of its type. It used action research as the research method and focus groups as data collection instruments. Regarding the Action Research method, as defined by Thiollent (1988), "it is a type of social research based on empirical evidence that is conceived and carried out in close association with an action or resolution of a collective problem, in which researchers and participants representing the situation or problem are involved cooperatively or participatively" (p.14).

According to Gil (2010), this method is more challenging to present in temporally ordered phases. However, as described in the next paragraph, the present research involved researchers, a team of students, teachers, and school management professionals in direct and active contact to disseminate and implement maker culture, making this method appropriate.

Focus groups are a method that allows data collection through interviews conducted by a moderator (MATTAR, 1996). This method generates hypotheses and will complement the Action Research process. Focus groups will be where the perceptions of the actors involved in the research will be detailed and, according to observations, measured to indicate the impact and effectiveness of the activities carried out.

The research field was the Maker Space, located at the Federal Institute of Espírito Santo, Cariacica campus, and Municipal Schools in the City of Cariacica, where 9th-grade students and teachers will be invited to participate in the research process. Throughout the process, the research may also take on characteristics of Extension.

Within the possible limits of the moment, the end activities of this project consist of three phases: researcher and team training, field trips to conduct workshops in municipal schools in Cariacica, which will constitute the research field and guidance and collection of perceptions from those involved.

The following procedures were implemented to systematize the work proposal to achieve the objectives.

Phase 1. Considering the project's resource viability definition, students from the Technical Course in Administration and the bachelor's degree in production engineering were trained, along with IFES teachers, to carry out the proposed activities. They became proficient in using software and manipulating 3D printers and received training to present workshops to the target audience.

Concurrently, the Maker Space underwent adjustments and modifications to be used by the team constantly and subsequently serve the external public. The directors of the municipal schools will be invited to IFES for a project presentation. The schools will be selected based on accessibility and availability.

At the end of this phase, a pilot activity should take place in one of the schools.

Phase 2. After the pilot activity is carried out and evaluated, actions will focus on the other schools to be served. During regular IFES class hours, the students involved will continue to use the Maker Space, developing skills and producing pieces on 3D printers that will be distributed as gifts and incentives to students from municipal schools during workshops. Workshops will last for 3 hours, in addition to 1 hour of lecture, which did not necessarily have to take place on the same day but should precede the workshop.

IFES teachers will talk to teachers and directors of schools to present the possibilities of using the IFES Maker Space by school students on scheduled visits.

Phase 3. The team's collection of perceptions from the visited schools characterizes this stage.

Through the conduct of focus groups, it was identified how the project impacted the school through questions such as:

• How much did the experience change students' perception of their school environment?

• What is the perception of managers and directors about the applicability of technology in their classes?

This project focused on municipally managed schools, which have fewer resources and need more significant support for fostering students' expectations and motivations.

The research field will be the IFES Cariacica campus and its Maker Space for training those involved and use by students. In addition to the Municipal Elementary Schools in Cariacica, it focuses on the 9$^{th}$ grade through lectures and workshops.

# 4 Results

The results presented here represent a part of the scope of this research. We chose to present the entire proposal to facilitate understanding of the context. The study is ongoing, and new data will be published later.

The main results presented here represent two schools designated as the "pilot project." The experience gained will be applied to the other schools the project will serve.

## 4.1 Participants

The first activity involved presenting and encouraging the participation of schools:

- In March 2022, visits and meetings were conducted with the directors and teachers of two municipal schools to clarify and organize the project.
- In April, workshops were conducted with the teachers on Maker Culture, Prototyping, and Additive Manufacturing at the Maker Space on the Cariacica campus.
- From April to September, workshops were conducted with the students on Maker Culture, Prototyping, and Additive Manufacturing at the Maker Space on the Cariacica campus.
- The project reached two schools, involving 12 teachers and 167 students.

## 4.2 Comments

The project sparked the development of new skills among those involved:

- For students: Skills in Programming, Computer-Aided Design, Data Analysis, and Interpersonal Relationships.
- For teachers and school principals: Awareness of the relevance of maker culture and active learning methods in schools.

The experience demonstrated how the introduction of new technologies in the lives of elementary school students sparked an interest in seeking new knowledge and a vision of new opportunities for educational, personal, and professional development. Students designed and printed their product ideas (gifts, toys). This opportunity also awakened skills in some students that they still needed to develop. The project also involved the participation of students with specific learning needs, such as Autism and Down Syndrome.

The activities throughout the project showed how Maker Culture, especially 3D Printing, is accessible and viable for fostering and stimulating the interest of students and teachers, promoting more participatory classes.

Regarding campus scholarship students, it was observed how the integration of knowledge about Additive Manufacturing not only created a new perspective on work through new technologies, expanding the vision of opportunities for the use of Additive Manufacturing-related tools, but also stimulated the use of this technology in the development and application of both technical and Core Curriculum disciplines in their courses of study.

# 5 Final Remarks

It is important to emphasize that this research outcome is part of a project that began in 2022. It has limitations, and new data and information will be presented in subsequent publications.

Continuing with the project, the aim is to capture the potential transformative experiences among the research participants.

For the community served, represented by the schools, the Maker Space at IFES Cariacica will remain accessible as a reference center for rapid prototyping, 3D printing, dissemination of maker culture, and encouragement of PBL practices.

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# STEAM Classrooms: A Neuroscience-Based Educational Transformation Experience within UNAL's Digital Framework

Liz Karen Herrera-Quintero[1], Juan David Villegas-Tamayo[2], María Fernanda Lara-Diaz[3]

[1] Department of Mechanical and Mechatronic Engineering, Faculty of Engineering, Universidad Nacional de Colombia.
[2] STEM -FABlab Classroom Sede Manizales Universidad Nacional de Colombia.
[3] Human Communication Department, Faculty of Medicine, Universidad Nacional de Colombia.

Email: lkherreraq@unal.edu.co, jdviillegast@unal.edu.co, mflarad@unal.edu.co

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**Abstract**

The National University of Colombia (UNAL) has successfully integrated a STEAM (Science, Technology, Engineering, Arts, and Mathematics) curriculum across its campuses in Manizales, Tumaco, Medellin, and Bogota to foster inclusivity and reduce student dropout rates. This initiative, spearheaded by the Academic Directorate and supported by the University Laboratory Division, leverages insights from neuroscience and neurodidactics to craft learning experiences that enhance both cognitive and emotional aspects of student learning. The expansion of the STEAM-Fablab classrooms through the Inter-Campus Laboratories Collaboration Network has promoted creativity, co-innovation, and technological development, significantly strengthening digital competencies within the UNAL community. Tailored methodologies address the unique needs of each campus, with specialized training sessions ranging from 3D printing and CNC machining to knowledge management and extended reality. Local adaptations ensure relevance, such as sensor technology for marine system monitoring in Tumaco, sustainability designs in Medellin, and additive manufacturing for artistic development in Bogota, showcasing a dynamic, interdisciplinary approach to education that prepares students for future challenges.

**Keywords**: Active Learning; Engineering Education; Neuroeducation; Neurodidactics; STEAM.

## 1 Introduction

La Universidad Nacional de Colombia (UNAL) is committed to promoting the quality of education in science, technology, engineering, arts, and mathematics (STEAM). This objective seeks to reduce dropout rates and project education by harmonizing its mission functions: teaching, research, and outreach. Thus, activities that promote the learning of skills and competencies for the present and the digital future are encouraged from training.

Scientific and technological advances have influenced the promoting of these skills and competencies and pedagogical and didactic changes. Thus, evidence-based education is defined as educational information and action based on reports and scientific studies that help us make better decisions in the educational field (Slavin, 2002). Thus, academic actions and decisions are impacted by science.

In this context, neuroscience has emerged as an invaluable tool in education, offering an increasingly deep understanding of how the brain functions during learning, establishing the neural mechanisms underlying cognition, including skills such as attention, memory, creativity, reasoning, and language. As a meeting point for different disciplines, neuroscience provides a scientific foundation for developing more effective and personalized pedagogical strategies. Thus, integrating neuroscientific findings into educational practice optimizes the teaching and learning process and opens new frontiers to address complex educational challenges and promote comprehensive student development. To facilitate understanding in both the public and academia, the term "neuroeducation" has been used.

The goals of STEAM education include promoting STEAM literacy and preparing students for complex changes in the real world (Zollman, 2012). Integrating science, technology, engineering, and mathematics into authentic contexts can be as complex as the global challenges that demand a new generation of STEAM experts. Teachers need help to establish connections between STEAM disciplines. Consequently, students often show little interest in science and mathematics when they learn in isolation and disjointedly, without connections to cross-cutting concepts and real-world applications. This requires a conceptual framework to guide the actions of teachers and experts designing educational policies and programs (Kelley & Knowles, 2016).

To engage students in STEAM education, it is necessary to foster scientific research, have a rigorous curriculum, and integrate technology into these plans (Kennedy & Odell, 2014).

The Academic Directorate of UN Manizales Campus has been implementing strategies over the past few years for transitioning to spaces involving STEAM teaching-learning methodologies, focusing on the university community, and reaching students from different secondary schools nationwide through various learning outreach programs. The goal is to attract future graduates to pursue careers in this field. Among these strategies is the design and implementation of an academic workspace, managed from a central level of the University, equipped with pedagogical tools for the formulation and execution of projects within the framework of 4.0 technologies. This space (STEM Classroom - Manizales Campus FabLab) was created to support students and the university community in developing interdisciplinary academic activities involving topics from different subjects, where science, technology, engineering, and mathematics can be integrated into learning.

Thus, this study presents a learning methodology implemented by the STEAM classroom. This methodology has as its pillar the student's interaction with the different mental processes carried out in acquiring knowledge, allowing them to be directly involved in research and development of solutions.

Evidence from studies in neuroeducation has found differences between traditional education and education in which STEAM classrooms have been implemented. The main findings are that our brains synchronize in STEAM classrooms (Davidesco, 2020), and students are more sociable (Linton et al., 2014).

Goswami (2018) believes better teacher teaching is required for better student learning. Thus, neuroscience provides tools that contribute to improving educational practices. Below are three proposed principles for this (Blakemore & Frith, 2011). They are firstly, designing more effective and meaningful learning experiences for students. This involves considering the cognitive and emotional processes that occur in the brain during learning. Secondly, connecting concepts with students' previous experiences creates a bridge between the familiar and the new, thus facilitating learning and information retention; and thirdly, promoting collaboration and critical thinking, which contribute to jointly constructing active learning through reflective and objective information analysis processes.

Therefore, in the UNAL STEAM Classrooms, integrated practices are carried out in which explicit connections are made, meaning that students must understand how STEAM knowledge applies to real-world contexts. Additionally, support is provided for them to generate ideas, relate them productively, and reorganize them in a way that develops information reformulation processes, reflecting normative scientific practices. This combines stimulating experiences, critical thinking skills, increased attention spans, and problem-solving.

A learning activity's physical and social contexts are crucial to the learning process. This is where situated learning comes into play. Learning based on a situated context becomes authentic and relevant, representing an experience encountered in actual STEAM practice (Putnam & Borko, 2000). When considering the integration of STEAM content, engineering design can become the situated context and platform for STEAM learning.

Figure 1. STEAM Classroom at the Medellín Campus.

## 2 Methods

The objective has been to create a collaboration network of inter-campus laboratories to strengthen creativity and digital skills by establishing three immersive STEAM satellite classrooms in the Tumaco, Bogotá, and Medellín campuses. To enrich project-based learning methodology through neurodidactics, methods that activate information processing, reinforcement in working memory, reasoning, questioning, and practicing what has been learned are necessary to make the learning process efficient (Dunlosky et al., 2013).

Through this methodology, the aim is for students to take the lead in their learning journey. They will engage in independent research development, where they can develop skills and knowledge focused on the STEAM field, learn to use cutting-edge equipment, and produce innovative and viable ideas in response to the challenges that arise in their respective environments. In this way, the educational process allows for exploring various disciplines in an integrated manner and develops vital competencies such as critical thinking, collaboration, and effective communication.

### 2.1 Neurodidactics

Neurodidactics defines *learning* as: "Any variation in synaptic connections that produce changes in thought and behavior. Modifications can occur through theoretical information, practice, or life experiences" (Paz et al., 2018). Neurodidactics responds to the following basic principles, which should be considered in this methodology (Ozden & Gultekin, 2008):

- Motivation in students is essential to achieve their learning.
- To achieve authentic learning, involving students in the processes is necessary.
- Learning requires respect for students' rhythms, interests, states, and needs.
- Learning requires research, meaning-making, reasoning, and understanding.
- Each student's emotions are deterministic factors in learning.
- The role of mirror neurons in learning is undeniable.

This methodology is not just a theoretical concept but a practical tool to make information reach students more effectively. It is designed to steer learning towards each person's meaningful long-term memories, transforming them into lasting knowledge. A study conducted by MIT (Poh et al., 2010) provides concrete evidence: students in a traditional classroom-only partially activate their brain capacity compared to when the teacher involves them in project development, as in the methodology proposed here.

An essential element, according to experts, for learning is motivation. The brain process of motivation is known as DAS, where neurotransmitters such as dopamine, adrenaline, and serotonin are activated (Chávez & Chávez, 2020).

Below is how the methodology proposed in this article intends to cover the brain's motivation process:

**Desire:** Finding a simple solution to a problem.

**Action:** Designing and establishing the requirements to have the best solution.

**Satisfaction:** Applying the solution to the problem posed.

| Brain process of motivation | | |
|---|---|---|
| Desire | → | Dopamine |
| Action | → | Adrenaline |
| Satisfaction | → | Serotonin |

Figure 2. Brain process of motivation.

In summary, this strategy aims to understand and enhance students' skills. Without losing sight of motivation, learning is characterized by being both a cognitive and motivational process simultaneously (Schultz W., 2015).

# 3 Procedure

## 3.1 Learning with STEAM Methodologies

By establishing STEAM Classrooms at the Bogotá, Medellín, and Tumaco campuses, we are not just meeting the need for comprehensive learning in science, technology, engineering, art, and mathematics in these communities. We are creating innovative spaces to provide training opportunities and develop technological, creative, and collaborative skills. These spaces will foster innovation and entrepreneurship, generating real solutions to current challenges. Moreover, by integrating environmental themes, we will raise awareness and contribute to environmental conservation, promoting sustainable development in the regions. This initiative can potentially transform these communities, inspiring a brighter future.

Figure 3. 3D Printer Use Training.

The STEAM methodology for learning development is based on the successful experience of the STEM-FabLab Classroom in Manizales, adapted to the particularities and needs of each campus. Key aspects such as strategic planning, resource identification, specialized personnel selection, and acquisition of equipment and technologies are addressed. The development of the STEAM Classrooms promotes technological development and skills training in the cities of Bogotá, Medellín, and Tumaco, strengthening the innovation ecosystem and creating opportunities for the personal and professional growth of the participants. Project-based methodology and knowledge transfer are expected to impact the university community positively. The goals of this process are:

- Application of technological solutions that improve quality of life and promote local progress.
- Comprehensive training of professionals in STEAM areas.
- Promoting employability.
- Entrepreneurship in the business sector.
- Strengthening the innovation ecosystem.
- Generating development opportunities.
- Social transformation.

## 3.2 Enhancing STEAM Learning with Neurodidactic Principles

The relationship between the inter-campus STEAM classrooms at the National University of Colombia (UNAL) reflects a teaching and learning methodology that addresses the specific needs of diverse communities and territories. A central aspect of this methodology is the integration of neurodidactics, which leverages principles of neuroscience to optimize learning processes in STEAM disciplines. This approach has proven to have a significant impact on how students acquire and process knowledge. Below, several key strategies are outlined:

Personalization of Learning: By employing neurodidactics, UNAL educators can identify and respond to students' differences and needs across various knowledge domains. This enables the design and implementation of strategies, activities, and projects tailored to diverse learning styles, enhancing the educational experience in STEAM spaces.

Enhancement of Retention and Comprehension: Neurodidactic principles emphasize the importance of emotion and motivation in learning. In STEAM classrooms, where concepts can be particularly complex and challenging, applying techniques that create emotional connections with the study material can significantly improve content retention and understanding.

Development of Critical and Creative Thinking Skills: Neurodidactics promotes methods that stimulate critical and creative thinking, which are essential in STEAM. Students can develop these crucial skills through practical problem-solving and interdisciplinary group projects, driving innovation and creative problem-solving.

Encouragement of Curiosity and Exploration: Applying neurodidactic principles in STEAM teaching helps design lessons that foster exploration and curiosity. This is particularly valuable in fields such as science and engineering, where discovery is key to learning.

Integration of Learning Technologies: Neurodidactics also guides the integration of emerging technologies in the classroom, such as virtual reality, simulations, and interactive platforms. These tools can make abstract concepts more tangible and accessible to students.

Implementing these practices in UNAL's STEAM classrooms improves the quality and effectiveness of learning. It prepares students to tackle future challenges in their fields innovatively and adaptively.

## 3.3 Learning Areas and Lines

Each learning line aims at one or more areas worked on in STEAM so that all classroom members, regardless of their career, can develop new skills that nourish interdisciplinarity and thus create synergy between all fields of action. This allows projects to be built and strengthened from different angles, utilizing insights from neurodidactics to enhance cognitive engagement and emotional connectivity with the content, ensuring that learning processes are effective and retained over time.

- Extended Realities: Explore and experiment with virtual, augmented, and mixed reality technologies. Learn to develop immersive applications and content, applying design, programming, and digital narrative concepts. Neurodidactic strategies maximize sensory and experiential learning, facilitating more profound understanding and memory retention.

- Internet of Things (IoT): Students delve into connected devices and machine-to-machine communication. Learn to design and program IoT solutions, implementing sensors, actuators, and simulation platforms. The curriculum incorporates principles of neuroeducation to enhance problem-solving and critical thinking, which are essential for innovating in IoT.
- Machine Learning: Participants discover the fundamentals and applications of machine learning. Explore algorithms, data analysis techniques, predictive model development, and their application in different contexts and issues. Lessons are designed to align with cognitive patterns that foster analytical thinking and comprehension, supported by neurodidactic approaches.
- Programming: Students develop programming skills in Python, JavaScript, C++, and more. They learn to design and build applications and technological underpinnings, applying good programming practices and problem-solving. Neurodidactics structure learning sequences that progressively build on existing knowledge, enhancing logical reasoning and coding efficacy.
- Electronics and Circuits: This learning line delves into electronics and circuits, from understanding essential components to building and programming electronic circuits. Participants acquire skills in circuit design, soldering, and laboratory tools. Teaching methods are adapted to foster hands-on learning and spatial reasoning, which are critical in electronics, through neurodidactic principles.
- 3D Modeling: This area delves into three-dimensional modeling using specialized software. Learn to create and modify objects in virtual environments, applying design and rendering techniques for prototyping and projects. The pedagogical approach leverages visual and spatial learning strategies derived from neurodidactics, enhancing mental visualization and manipulation of objects.
- Architecture and Design: This course explores the fundamentals of architecture and design, focusing on applying innovative technologies and methodologies. Participants learn to create functional spaces and objects, considering aesthetics, ergonomics, and sustainability. Neurodidactics informs the integration of sensory experiences in design education, facilitating a deeper understanding of the interplay between form, function, and environmental impact.

Figure 4. STEAM Event in Bogotá to contextualize classroom work.

# 4 Results

## 4.1 Development of Training Processes

A series of virtual training sessions via YouTube was conducted to ensure effective knowledge transmission, activate motivation, and ensure adequate learning processes. These sessions, led by experts in each topic, covered various emerging technologies. The sessions were divided into theory and practical exercises, providing a comprehensive learning experience. Prior to these sessions, all participants voluntarily registered, confirming their consent to use the data to monitor and evaluate the effectiveness of the training.

Initially, student interest was attracted through the presentation of innovative and successful projects that have taken place in the STEM Classroom at the UNAL Manizales campus. This allowed students to observe the scope of their ideas and how they can scale up to become viable and marketable products.

Subsequently, agile methodologies and soft skills were addressed as pillars for time management, faster project completion, and the use of digital tools necessary for task management. With these foundational training sessions, an introduction to more specific topics was given, such as:

- Entrepreneurship and innovation in STEAM addressed the necessary steps to start a successful business.
- Design and sustainability-focused on using renewable energies to produce electricity in hard-to-reach areas.
- Technologies for digital transformation, directed towards data science, formulated a simple project that included using Python and a database to relate similar concepts and provide conclusions.
- Extended realities cover the types of realities (real reality, augmented reality, virtual reality, mixed reality), their operations, and a step-by-step example of approaching the use of Unity as a development engine to generate applications focused on these topics.
- Design and artificial intelligence focused on using AI to facilitate and expedite the creation of graphic pieces, their advantages and disadvantages, possible advances, and risks.
- Intellectual property in project management, the proper registration of projects, the difference between intellectual property and patents, the problems that AI produces in these cases, and the types of innovation.
- Sensory and industrial processes: This section explains the types of sensors used for factory monitoring, provides examples of use, and includes a practical exercise carried out online.

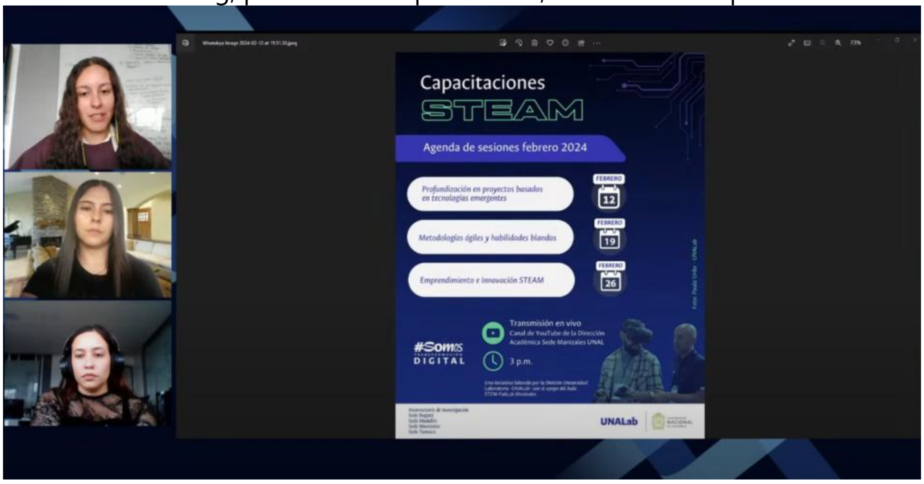


Figure 5. Training "Deepening of projects based on emerging technologies.

For these training sessions, a previous voluntary registration of 1200 people from all campuses of the National University of Colombia was made, of which a total of 3465 views were achieved and a session rating of 314 people. Several strategies were implemented to assess and enhance the participants' learning experience. At the end of each session, a satisfaction survey was conducted to gather feedback and perceptions on the effectiveness of the training. Additionally, questions and concerns from participants were actively addressed during the sessions, ensuring dynamic interaction and continuous support.

To measure the knowledge acquired more objectively, interactive Kahoot quizzes were used. These quizzes, conducted at the end of each session, allowed for the assessment of information retention and provided immediate feedback to both instructors and students on the concepts learned.

Furthermore, step-by-step follow-along exercises were incorporated to foster a practical and deep understanding of the topics covered. These exercises were designed for participants to apply what they had learned in practical situations, thus strengthening their familiarity and proficiency with the discussed tools and concepts. These evaluative and participatory activities increased interaction during the sessions. They provided valuable data for continuous improvement of the content and teaching methods, ensuring that the learning objectives were effectively met.

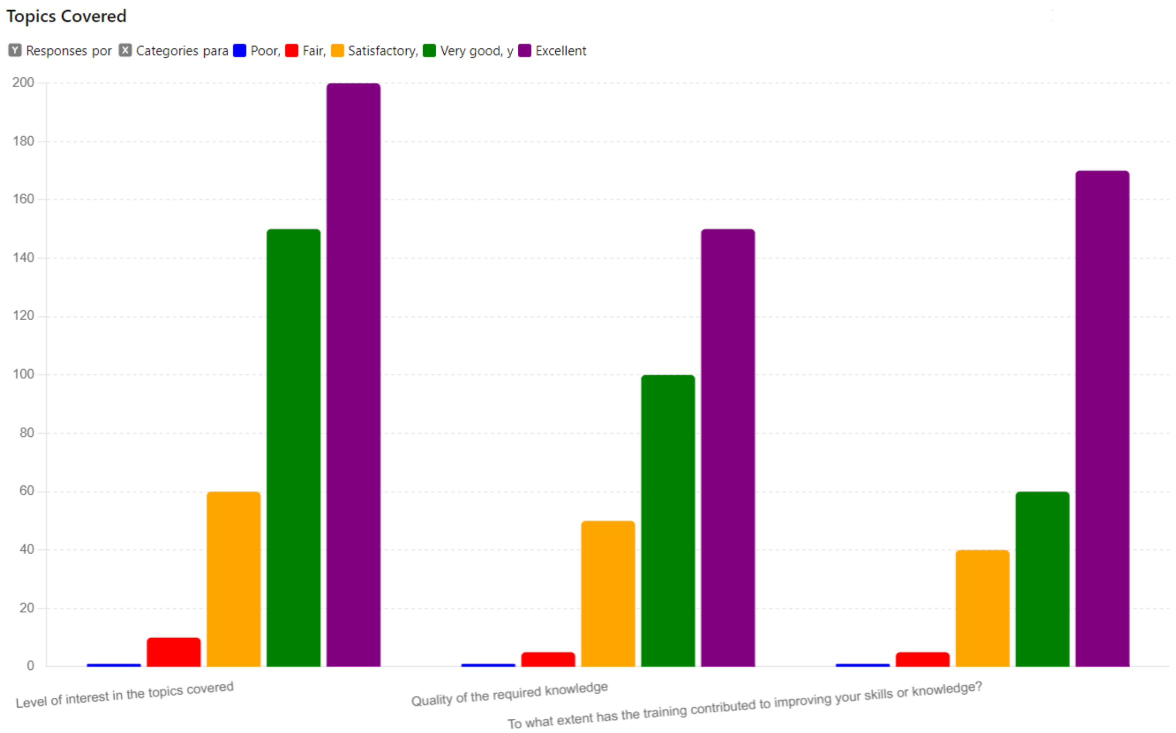


Figure 6. Raining qualification statistics

## 5 Discussion

The National University of Colombia training sessions are designed to leverage neurodidactic principles to optimize learning environments and enhance cognitive engagement. This approach aligns with the principles of neuroscience that focus on how the brain learns, ensuring that teaching methods are not only effective but also resonate with the brain's natural learning processes. The data presented in the bar chart provides an insightful evaluation of how these principles impacted the outcomes.

### 5.1 Analysis of Survey Results

Level of Interest in the Topics Addressed: High ratings in 'Excellent' reflect significant enthusiasm and cognitive engagement, essential components in neurodidactic strategies. A high level of interest is crucial as it is associated with increased neural activity in brain regions related to attention and memory, enhancing the overall learning experience.

Quality of Knowledge Required: The feedback ranging from 'Satisfactory' to 'Excellent' suggests that the sessions successfully met cognitive expectations and were well-tailored to the participants' levels of understanding. This aligns with neurodidactic practices that emphasize aligning educational content with the learners' cognitive development stages and prior knowledge.

Contribution to Skill or Knowledge Enhancement: Predominantly, 'Excellent' ratings in this category indicate that the sessions highly strengthened neural connections related to the skills and concepts discussed. This effectiveness is a core goal of neurodidactic approaches, which aim to facilitate durable learning and retention by engaging multiple neural pathways.

### 5.2 Impact of Neurodidactic Strategies

Interactive quizzes on Kahoot and structured follow-along exercises are practical applications of neurodidactic theories. These tools not only actively engage learners but also provide immediate feedback, which is known to reinforce neural pathways and facilitate the consolidation of new knowledge. The quizzes assess information retention and adjust teaching tactics in real-time, while the exercises promote the application of knowledge, ensuring deeper neural encoding and retrieval pathways.

### 5.3 Participant Interaction and Neuroplasticity

Addressing participants' questions and concerns during the sessions contributed to creating a responsive learning environment that adapts to the learners' needs, another key aspect of neurodidactic teaching. This adaptive learning environment supports neuroplasticity, the brain's ability to reorganize itself by forming new neural connections in response to learning.

## 6 Conclusion

Adopting pedagogical approaches based on a deep understanding of brain functioning during learning has designed more effective and meaningful teaching experiences. This commitment to neuroeducation allows for addressing students' cognitive and emotional needs, optimizing information retention, and promoting critical skills such as critical thinking, creativity, and problem-solving.

The STEAM methodology, in turn, has been implemented through interdisciplinary projects that connect science, technology, engineering, arts, and mathematics, providing authentic and applicable learning contexts. This approach improves student interest and participation and prepares them for the complex challenges of the real world, thus promoting comprehensive and applied education. These methods have made the learning process more enjoyable and engaging and enhanced the cognitive and emotional resonance of the content, which are critical for deep and lasting learning. The results affirm that applying neurodidactic principles in STEAM education can significantly enhance the immediate understanding and the long-term retention of complex concepts, fulfilling the strategic educational goals of the National University of Colombia.

The UNAL STEAM Classrooms are a clear example of how integrating these methodologies can transform the educational environment. They provide a space for experimentation, research, and the development of innovative technological solutions. These classrooms represent a step forward in STEAM education, allowing students to learn in a theoretical context and apply their knowledge in practical projects that reflect current and future challenges.

**Acknowledgments**

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# Pedagogical Strategies to Stimulate the Active Participation of Students in Mathematics Classes in Higher Education.

Julián M. Granados[1], Mariana Henao[1], Diego A. Castrillón[1], Maria P. León[2, 3], Carola Hernández[3]

[1] Facultad de Ingeniería, Institución Universitaria de Envigado, Envigado, Colombia
[2] Facultad de Ingeniería, Pontificia Universidad Javeriana, Bogotá, Colombia
[3] Facultad de Ingeniería, Universidad de los Andes, Bogotá, Colombia

Email: jmgranados@correo.iue.edu.co, mhenao@correo.iue.edu.co, dacastrillon@correo.iue.edu.co, mpleon@javeriana.edu.co, c-hernan@uniandes.edu.co

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**Abstract**

The most common pedagogical practice in teaching Basic Sciences in Engineering programs is the teacher-centered practice, which, through master classes, exposes the theoretical foundations and proposes exercises to strengthen students' knowledge. In these classroom environments, there are limited opportunities for student participation, and students must mostly attend to the teacher's explanations. Active learning pedagogical practices are often challenging to apply in this course. In this sense, at the University Institution of Envigado, we ask ourselves: How do we encourage evident student participation to identify progress in learning? The methodology used in this work is Critical Research (Skovsmose & Borba,2004), in which three analytical situations are proposed: the current situation, the imagined situation (hypothetical situation or solution), and the fixed situation (realistic scenario of the imagined situation). Three negotiation processes: 1. pedagogical imagination, 2. practical organization, and 3. exploratory reasoning, make the three situations proposed in the model possible. In the current situation, it is identified that the generation of environments of trust fostered by the teacher, the generation of spaces for decision-making by the students, and the understanding of the subject are elements that encourage the participation of the students. However, these pedagogical strategies are not present in a generalized or structured way in all introductory science courses. In the imagined situation, pedagogical strategies are designed to increase the student's evident participation in classes. In this way, it is expected to generate an environment of trust that motivates the participation of students, changing their role as active agents in the learning process.

**Keywords**: Participation; Active Learning; Critical Research; Basic Sciences in Engineering.

## 1 Introduction

The Institución Universitaria de Envigado (IUE) has developed an action plan that seeks to carry out curricular transformations to align learning outcomes with the competencies and training profiles declared in the faculty programs. One of the institutional strategies outlined in this plan involves training teachers to design class activities that are truly aligned with the specific learning outcomes of each course. This process coincides with some situations identified by teachers of Basic Science courses associated with students' difficulties in understanding the concepts addressed, leading to limitations in their ability to analyze and interpret information or apply concepts in new contexts. As part of the institutional plan, several professors are sent to attend the New Alternatives in Engineering Education Course at Los Andes University, where the opportunity to rethink pedagogical practices in the Faculty of Engineering of the IUE is identified. Professors and researchers from both institutions materialize the intention to work on teaching transformation processes through the inter-institutional research project "Development and implementation of active methodologies in the area of the calculus of the Faculty of Engineering at the University Institution of Envigado" in which intervention strategies are designed to generate student-centered teaching processes for the courses Differential Calculus, Integral Calculus and Numerical Methods that are part of the basic cycle of the Electronic Engineering, Industrial Engineering and Computer Engineering programs.

This work is based on contemporary sociocultural educational theories and, therefore, emphasizes the importance of student participation in learning. In particular, it follows Wenger's approach (Wenger, 2001), where learning is assumed to be a social process that involves negotiating meanings. This process transforms the relationship between subjects and the world and simultaneously generates identity. It also considers the vision proposed by the theory of objectification (Radford, 2023), in which learning is understood as a collective cultural-historical process that creates spaces for construction between teacher and students in which both cooperate in different and complementary ways. On the other hand, students' participation in the class can be evidenced by cooperation and involvement, questioning, quality of answers, contribution of conclusions, and work in front of the class (Lo, 2010). Following objectification theory, actions demonstrating student participation should also involve elements such as identifying reflective subjects with critical positions in the face of mathematical discourses and practices to consider new possibilities for action and thought (Radford, 2023). Wenger refers to such participation as evident participation (Wenger, 2001).

Despite the results reported in a good number of studies related to the improvement of learning and knowledge retention (Handelsman et al., 2004), in general, there is considerable resistance to the implementation of active learning strategies in classes related to science education, as is the case of Basic Science courses at the IUE. According to (Handelsman et al., 2004), some university professors do not feel the need for change because current educational systems have produced excellent scientists, others are intimidated by the idea of implementing new pedagogical strategies, or they may even fear that identification as professors will affect their credibility as researchers.

Based on the above approaches, the team of researchers and professors participating in the inter-institutional research project developed at the IUE, whose objective is to transform pedagogical practices for the development of student-centered teaching-learning strategies in engineering programs, have formulated the research question: How to encourage the evident participation of students to identify progress in learning?

## 2 Critical Research

The research project uses the critical research methodology (Skovsmose & Borba, 2004) in which the transformation of pedagogical practices starts from the Current Situation in which those characteristics that occur in the classroom before the intervention are identified. Based on the theoretical constructs guiding the project, such as the conception of learning and the educational experience of researchers and teachers, intervention strategies are then designed, leading to the Imagined Situation. Implementing the strategies amid specific conditions and constraints results in a Fixed Situation that is not expected to coincide with the imagined situation.

Critical research is characterized by its interest in change, so it places particular emphasis on those things that do not happen in the classroom but could happen. This approach is especially interesting in the imagined situation because the construction carried out by researchers and professors mediates between current and fixed situations. The processes involved in transforming one situation into another allow us to understand the contributions of critical research. The process of pedagogical imagination offers the possibility of exploring conceptual alternatives to the current situation, thus generating an imagined situation. The process of Practical Organization includes all those actions and negotiations carried out by researchers, teachers, students, and administrators to implement the strategies designed in the imagined situation. However, for various reasons, these actions do not necessarily result in obtaining the imagined situation as designed, and practical organization can be described as "a realistic, and perhaps pragmatic, version of the pedagogical imagination" (Skovsmose & Borba, 2004, pp 208). Exploratory reasoning, on the other hand, allows us to analyze the viability of the imagined situation based on the observations and evidence recorded in the arranged situation (See Figure 1).

Cooperation between researchers, teachers, students, and administrators is essential to carrying out each of the processes. Acknowledging cooperation in this way shows that in critical research, professors and students participate in research and do not become objects of investigation. This cooperative research is aligned with the socio-cultural theories of learning used as a reference for the pedagogical actions designed and implemented within the framework of the research project presented in this work.

In the research project developed at the IUE, the current situation is established from the records of observations in classes and surveys carried out during the 2023-1 semester to students in which it is sought to identify the level and type of participation that occurs in the classes, as well as the pedagogical strategies that generate it. At the beginning of the 2023-2 semester, a focus group was held with professors of some Basic Science subjects of the Engineering programs. Their perceptions of student participation in class are inquired about, and the records of observations and surveys are socialized. The activities and reflections carried out in this focus group give rise to imagined situations for each teacher based on the needs of their courses. After participating in the focus group, some teachers design intervention strategies to stimulate student class participation. At the end of the 2023-2 semester, a new focus group is held where teachers socialize their fixed situations and the observations made in implementing the designed strategies.

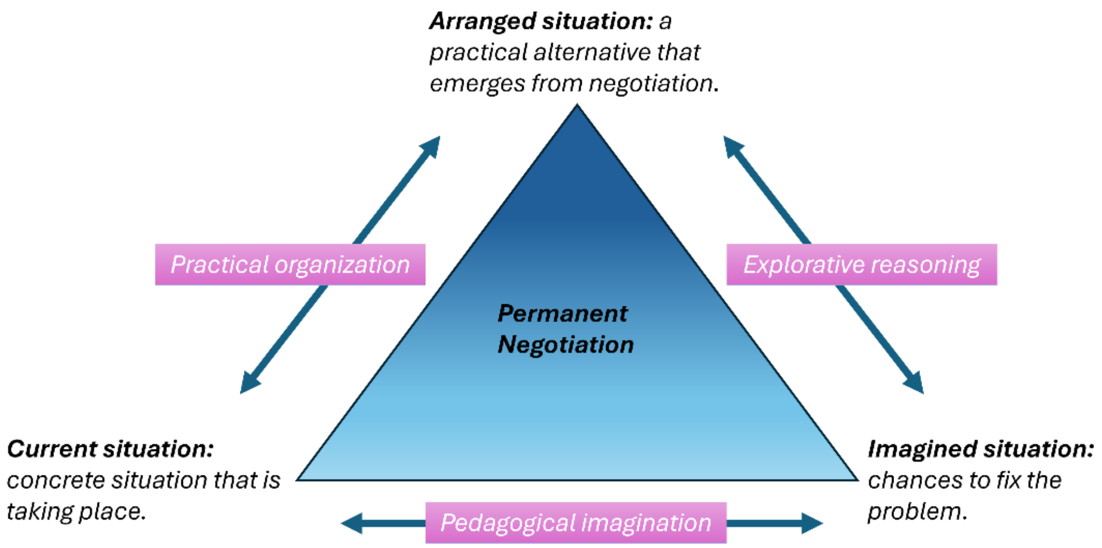


Figure 1. Critical Research Model, adapted from the figure presented by Skovsmove and Borba (2004).

# 3 Current situation

The introductory science courses of the Faculty of Engineering at the IUE use a traditional approach in which the detailed planning of the contents leads each teacher to use a master methodology to complete the objectives established for each class. Observations of classes from three different courses carried out during the 2023-1 semester allow us to identify two moments as common elements of the classes: the first moment corresponds to the explanation of the fundamental concepts of the theory, followed by the second moment in which the consolidation of the contents takes place by solving exercises that the teacher considers representative (Bustamante et al., 2023).

From the systematization of the observations, it is possible to describe the characteristic elements of the class environment in the groups. In the first moment of class, where the theoretical foundations and the steps to follow in the solution procedures are described, the students are attentive and take notes of the explanation the teacher writes on the board. The teacher often asks the students questions to assess their level of attention and comprehension of the explanations or prior knowledge. These questions result in short and often incomplete answers from some students. In the second stage, the students ask questions mainly related to the aspects of the solution procedures presented that are confusing for them. Sporadically, the teacher proposes activities to the students, such as going to the board to solve exercises or doing some work in teams during class. The teacher complements these activities with exercises assigned to the students so they can solve them outside the class and prepare them for the evaluation activities, which are primarily written and individual. The participation of the students is minor and is not necessarily generated by the activities proposed by the teacher. No significant changes were observed in the quantity or quality of the participations in the groups observed.

At the end of the 2023-1 semester, students were surveyed, and they were asked about their level of participation, how they participated, motivations, and barriers they identified to participate (Bustamante et al., 2023). From this information, it was concluded that the participation of the students consists firstly of *asking about the aspects that they do not understand of what the teacher explains, and secondly*, of *developing the class activities*. The option: *I do not usually participate in classes* ranked third, while the option *Propose alternative solutions to problems posed by the teacher* ranked fourth. The three main motivations for participating in class chosen by the students are in their order: *Understanding the topic being discussed in class*, *the usefulness or application of the topics*, and *class activities that invite participation*. On the other hand, the three main reasons that discourage student participation in class are *Not understanding the topic being discussed in class*, *The possibility of being questioned by classmates or the teacher,* and *A teacher's language that can become very technical*. These responses summarize the barriers students identify to participating in class activities. (¿Incluimos un enlace a la encuesta?)

However, in one of the groups observed, students showed greater participation, generating a classroom environment conducive to student-centered teaching. Within this group, students were actively engaged in asking questions, proposing alternative solutions, discussing exercise solutions, suggesting modifications, and taking the initiative to go to the board to perform specific procedures. The records of the observations make it possible to identify actions in the teacher that encourage student participation. The teacher is empathetic, which helps to build the confidence of the students in the class; he constantly asks them to select exercises to solve, making them an active part of the development of the class and recognizes the results obtained in the activities with which he stimulates the students to continue advancing in the assigned exercises.

The group of professors-researchers was concerned about what was happening in the classes of the professors who were not participating in the research. Therefore, it was decided to hold a focus group with all the professors at the beginning of the 2023-2 semester. In this focus group, similarities were identified in teaching methodologies, class moments, assessment practices, and student behavior in terms of class participation. The conversation started by investigating the teachers' perception of their students' class participation. Most of them stated that it was low and that it was challenging to generate it. They used statements such as: "*Students do not show a willingness to solve problems on the board*" and "*They do not share their doubts with the group or with the teacher during class, although the teacher provides a space to discuss them*". One of the teachers says that "*when some kind of challenge is raised, the students react*". For instance, this teacher assigns a bonus in a written assessment to the student who solves an exercise proposed in class. The professor adds, "*If an exercise is proposed without giving some kind of prize, no one leaves*" and concludes, "*Motivation starts with bonuses*". Another professor points out that "*the little participation in my classes generally comes from the same two or three students, although on some occasions these participations encourage other students to participate as well.*"

For a third teacher, student engagement increases as they progress through their training. Teacher number four says, "*When explaining some kind of exercise, I tend to intentionally make errors when explaining an exercise to expect some kind of intervention from the students. This has helped me a lot in my practice because I can identify whether those present are attentive or not.*" Teacher number 3 participates again in the conversation to point out two aspects. He highlights the importance of empathy with her students and assumes it is the act of working on self-esteem by getting emotionally close to her students. He ends by saying, "M*ost of my students complete their work not because they want to learn more, but simply to fulfill a duty*". These perceptions of teachers are consistent with student survey results and confirm student engagement orientation.

The observations are made in a group of each course. The characteristics of the students in each group are presented in Table 1.

Table 1. Characteristics of observed groups.

| Observed group | Semester | Class schedule | Number of students | Number of observed classes. |
|---|---|---|---|---|
| **Differential Calculus** | 2 | Daytime | 32 | 5 |
| **Integral Calculus** | 3 | Daytime | 18 | 4 |
| **Numerical Methods** | 5 | Daytime | 18 | 6 |

The IUE offers students two types of class schedules, daytime and nocturnal, which determine the schedules of the courses. In the daytime option, courses are offered between 8 am and 6 pm. In the nocturnal option, the courses can be enrolled between 6 am and 8 am or between 6 pm and 10 pm. All the groups observed correspond to the daytime option. The nocturnal option is designed for those students who are working, so it is expected that these students will be older than those in the daytime option, have less time available for their studies and be enrolled in the last semesters of their programs. Unlike the observations, the survey was carried out in all the groups of the courses Differential Calculus, Integral Calculus and Numerical Methods.

In conclusion of this current situation, teachers have noticed that only a few students are participating in the classes and some pedagogical strategies that promote participation are associated with the assignment of rewards to improve the results of individual written exams. Moreover, class activities correspond not necessarily to a particular conception of learning but rather to factors such as student attention during teacher explanations. This current situation and the reflections made by researchers and teachers lead to the research question: How can the evident participation of students be encouraged to identify progress in learning?

# 4 Imagined situation and pedagogical imagination.

The imagined situation arises from the process of pedagogical imagination. This process enables teachers to challenge the exercise of conceptualizing the possibilities of change in the classroom "because the existence of alternatives shows that the current situation is not a necessity" (Skovsmose & Borba, 2004, p. 208). The pedagogical imagination involves sociocultural knowing and knowledge present in the teaching-learning process, such as the teacher's understanding of the notion of learning, their knowledge about the students' educational particularities, and their knowledge about previous educational experiences.

Based on the reflections in the first focus group, the results of the class observations, surveys, and some of the theoretical concepts mentioned earlier in this work, the teachers are invited to implement actions that promote their students' participation. They are asked to record the participation generated in the classes to identify its impact on the learning processes. Reviewing the theoretical foundations of the project with the teachers of the focus group means that, in addition to the teaching experience, the pedagogical imagination involves conceptual elements that show that other situations are possible.

At the end of the focus group, several teachers expressed their intention to implement an intervention strategy, which allowed the teachers to identify the imagined situation. A first teacher admits to having difficulties getting closer to his students, so he decides to work on developing strategies that improve his empathy with the group. A second teacher shows interest in implementing strategies that include students in class decision-making, so he mentions the possibilities of proposing problems in the classroom and allowing students to select based on their interests. He even considers discussing with his students how to do some other class activities. Two professors expressed their intention to use collaborative work activities in the classes after reflecting on the concept of learning based on contemporary socio-cultural theories and understanding the need to promote a cooperative construction. The reflections made in this group are conversations in which the other teachers and researchers help each teacher clarify their imagined situation based on their experiences and knowledge of educational issues. As Skovsmose points out, the imagined situation occurs amid cooperative work based on negotiation processes, like the other situations.

# 5 Fixed situation and practical organization.

No meetings were held with professors during the 2023-2 semester. Each teacher carried out the monitoring of the intervention strategies through the observation of class dynamics, the photographic record in some cases and the construction of a field diary in others. At the end of the semester, a second focus group was held to learn about the results of the teachers' observation exercises and the possible implementation of strategies to encourage participation. The teachers agree that the exercise of the first focus group made them transform their methodology and the way they selected class activities because there was now an intention to generate participation.

The first teacher stated, "*From the previous meeting, I was very impressed by aspects related to empathy because that is complicated for me because affinity is more with some students than others, but now I try to get closer to other students. Now, I try to be attentive throughout the classroom and get everyone involved in the class dynamics. I am thinking, for example, of my Differential Calculus course because it is the one in which I have noticed the most changes, and it is the one in which I found it most particular that this semester has been different like they have studied. In this group, I have seen a greater willingness to participate than in others I have had.*" The second teacher mentions: "*With some activities, such as allowing them to choose the exercises to do in class, the position of some changed*".

A third teacher shares his experience in which he decided to implement collaborative work in his classes. "*I started proposing group assignments in class, and the participation increased, even from students who previously did not. Teamwork has led some students to take a leading role in explaining the solution procedures to their classmates.*". This activity changed the teacher's view of his students because, before this, he perceived apathy among some students who took an active role in collaborative work activities.

A fourth teacher also implements collaborative work activities in his classes, proposing exercises to be discussed and solved in teams. Some of the professor's conclusions are: "*I have observed that if collaborative work activities are carried out sustainably in several classes, spaces for discussion and reflection are fostered. I used to propose activities in teams to solve exercises years ago. However, without the look of collaborative work, I was frustrated to observe that most students wasted time doing things different from the proposals. I designed class activities this semester regarding the students' expected learning. This new approach makes that most of them use all the time in the class to work on the proposed activities*". Regarding teamwork, the professor indicates: "*The discussions are fascinating because they allow us to identify the students' gaps, the aspects that represent the greatest difficulty for them and the aspects that are being understood. I have understood that an attentive student in class is not necessarily learning, and more so, it is unclear to me what they understand and do not.*" The professor adds, "*I have noticed that some students understand topics better with their classmates' explanations than with me.*" In this case, collaborative work has led to spaces for participation in each team, which often becomes a general participation with discussions that involve all students.

The professor who led the group where student participation was observed expressed frustration. He could not obtain the same level of participation with a group in the 2023-2 semester. This group has 30 students enrolled, and the professor has used the same strategies that worked previously. However, in the group that showed successful pedagogical strategies, only 17 students were enrolled, making it easier to encourage student participation. The teacher's methodology encourages participation in his groups, which means that, unlike other teachers, he is struck by the fact that he does not have participatory classes. In the description of his successful experiences, the professor refers to the feeling of "*loss of control*" generated by participatory groups: "*Sometimes losing control is not bad, that is, losing control from the planning that is done is not so bad because there are classes that even when they are not within the planning that has been done for the day, They are very productive classes because the students themselves kind of direct it to what they have doubts, to what they need to learn and then you think I went through the class solving those doubts and I did not do the class.*" The teacher's description shows that the student's participation does not occur from the teacher's planning but from how much they consider that their learning needs can be met.

## 6 Exploratory reasoning and conclusions

The team of researchers and professors of the research project shared with the professors attending the focus group examples of actions carried out by other professors from the same faculty that encouraged participation in classes. Likewise, the results of the observations made in several groups and the surveys applied to students of Differential Calculus, Integral Calculus, and Numerical Methods were socialized. The information shared generated the conditions for a situation imagined in the specific conditions of each teacher. The reflections made in the first focus group showed the teachers that the activities planned for the classes do not necessarily encourage student participation so, according to the learning approach defined in this work, learning is not necessarily being generated. Teachers recognize that the few actions of students in classes have an extrinsic motivation associated with an interest in improving grades.

The teachers have not considered the importance of student participation in the teaching-learning process, which shows that this group of teachers has not reflected on what should be understood by learning. Consequently, class activities are not student-centered. Class observations and focus groups may even suggest that class activities are content-focused because some teachers express discomfort with the amount of content associated with each course, meaning they have to allocate less time than they consider necessary to address each topic in the class. The discussions generated in the first focus group fostered spaces of pedagogical imagination based on negotiation between teachers that led each teacher to select an intervention strategy.

In the second focus group, teachers share their observations. Despite not carrying out rigorous processes of recording information in the classes, their observations on the student's response to the proposed strategy show that there is an increase in the quantity and quality of participation in each intervention. Although some strategies had better results than others, with all of them, students began to mobilize, and some teachers could consider new pedagogical strategies because they observed evident changes in the classroom environment.

The pedagogical imagination produces a noticeable change between the current situation, in which the participation of a few students motivated by the intention of improving grades in the course is expected, and that obtained in the fixed situation, in which students are reported to participate in classes motivated by feeling included in the selection of class activities or because they feel comfortable in small work groups, or even, they feel in an environment of trust as a result of a teacher who works on improving their empathy with the group of students. The teachers' observations mention participations that generate greater integration and students who explain processes to others, which shows that more intentional actions on the part of teachers lead to different results, and this is possible in mathematics classes without losing the rigor in the processes.

During the 2023-2 semester, the professors who decided to intervene in their groups designed pedagogical strategies autonomously, based on the discussions held in the first focus group, and applied them at the time they considered appropriate. Among other reasons, the fact that they were not part of the research project team made it difficult to generate spaces for conversation that would allow them to follow up on these actions and enable additional negotiation and feedback processes. This partly explains that the results shared by the teachers in the second focus group reflect activities carried out in one or more classes, which does not allow for a new classroom environment. Nonetheless, this experience offers an opportunity to transform some pedagogical practices if the process described in this work continues rigorously and sustainably over time.

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# The closing of the gender gap in the fourth industrial revolution with a feminist focus in Colombia

Juan Sebastián Sánchez-Gómez[1], Angie Hernández-Fuentes[3], Libis Valdez[2,4]

[1] Universidad de Los Andes.
[2] Latin American and Caribbean Consortium of Engineering Institutions (LACCEI).
[3] Universidad Nacional de Colombia.
[4] UNITECNAR.

Email: jsesgomez@poligran.edu.co, ahernandezfu@unal.edu.co, decano.fadi@unitecnar.edu.co

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**Abstract**

The abstract addresses the issue of inequity and the gaps of inequality affecting youth and women in rural areas of Colombia, particularly in the context of the fourth industrial revolution. These entrenched disparities have been exacerbated by historical and structural factors, limiting the access of these groups to educational, employment, and technological opportunities. The fourth industrial revolution, marked by technological advancements such as automation and digitization, presents both challenges and opportunities for these marginalized segments of the population. Recent research indicates that including youth and women in fields of study such as engineering can be a key factor in improving a country's Gross Domestic Product (GDP). However, for this to be possible, addressing the systemic barriers they face in accessing education and technical training in rural areas is essential. This implies the need to invest in education programs, vocational training, and digital literacy initiatives that provide them with the skills and competencies necessary to actively participate in the digital economy. This research will examine and disseminate the inequity and gaps of inequality affecting youth and women in rural areas of Colombia. It will explore how their inclusion in fields such as engineering can contribute to the economic growth and development of the country in the era of the fourth industrial revolution. To illustrate this point, successful case studies at both national and international levels will be analyzed, serving as inspiring examples and guides for academia, society, and government in the effort to close these gaps and promote inclusive development in Colombia.

**Keywords**: Systemic barriers; Gender inequality; 4.0 technologies; Microsexism.

## 1 Introduction

The 2030 Agenda set the goal of 17 Sustainable Development Goals (SDGs), i.e. the member countries of the United Nations (UN) must meet these 17 SDGs by 2030 (Sánchez-Gómez, 2023). The Center for Sustainable Development Goals for Latin America and the Caribbean (COSD) has been measuring this compliance through the SDG Index since 2015 for this region. (CODS, 2020). This SDG Index follows the methodology of the Sustainable Development Solutions Network (UNSDSN, n.d.), validated by the European Commission (Sachs et al., 2019).

In the SDG Index, Colombia lagged in the fulfillment of SDG 5 on gender equality between 2015 and 2021 (Sánchez-Gómez, 2022), lag, which worsened in 2022 according to the SDG 2022 Index of the SDG CODS. Colombia went from an SDG 5 compliance score of 65.37 in 2015 to a score of 51.78 in 2022, showing an increasing lag in SDG 5 compliance. As a result, Colombia went from ninth position in SDG 5 compliance in the 2019 SDG Index to 13th position in the 2022 SDG Index (Centro de los Objetivos de Desarrollo Sostenible para América Latina y el Caribe (CODS), 2023).

Colombia's lag in meeting SDG 5 on gender equity demonstrates the existence of a 30% gender gap according to UNESCO in 2019 (UNESCO, 2019). This gender gap must be addressed from a Diversity, Equity, and Inclusion (DEI) approach (Merchán-Rubiano et al., 2023). Equity is understood as the elimination of barriers that impede access to education for ethnic and cultural minorities and people with disabilities (Salmi & Bassett, 2014), and Inclusion ensures that everyone is integrated without any condition whatsoever (UNESCO, 2017).

In the historical context of Colombia, as well as in many other parts of the world, entrenched disparities have been forged that have profoundly affected the access of youth and women in rural areas to educational, employment, and technological opportunities. Historical factors such as violence, inequity in land distribution, and political marginalization have contributed to creating a disadvantaged environment for rural communities in Colombia.

Historically, women in Colombia have suffered discrimination and marginalization, a reality that is accentuated in rural areas. Deeply rooted cultural norms and traditional gender roles have restricted educational and employment opportunities for women throughout the country. This exclusion has been particularly evident in technical and technological sectors, where women have faced even greater barriers due to lack of access to resources and opportunities, a situation that intensifies in rural areas, where options for education and employment are even more limited (CEPAL, 2023).

Furthermore, limited access to technology and technical training has exacerbated existing disparities. According to the Organization for Economic Cooperation and Development, the lack of digital skills and the technological gap can leave rural communities, especially women and youth, lagging in the era of the fourth industrial revolution (OECD, 2019).

In summary, the historical context and systemic barriers in Colombia have created a challenging environment for youth and women in rural areas, limiting their access to education, employment, and technology. Addressing these systemic barriers is essential to promote social and economic inclusion throughout the country and close gender and age gaps in rural areas of Colombia (OECD, 2020).

The fourth industrial revolution not only presents significant challenges but also promising opportunities to close the gender gap in rural areas of Colombia. According to the World Development Report 2019 by the World Bank, in the era of the fourth industrial revolution, the demand for digital and technical skills is constantly increasing. This underscores the importance of investing in education and training programs tailored to the needs of women in rural areas (World Bank, 2018). On the other hand, entrepreneurship support programs, providing access to financing, mentorship, and support networks, can empower women to start and manage their businesses in the technology field. According to Colombia's National Development Plan 2018-2022, female entrepreneurship is essential to promote economic and social development throughout the country (Departamento Nacional de Planeación, 2018). Furthermore, promoting female role models in the field of technology and engineering can inspire girls and young women in rural areas to pursue careers in STEM. According to the Global Gender Gap Report 2021 by the World Economic Forum, creating mentoring programs and extracurricular activities that foster women's interest and participation in STEM can help overcome gender stereotypes and promote greater diversity in these fields (World Economic Forum, 2021).

In summary, by investing in education, training, entrepreneurship, and female role models, Colombia can harness the potential of women as agents of change and promoters of inclusive and sustainable development throughout the national territory. This will not only benefit rural women but also contribute to the country's overall economic growth and social development.

# 2 Methodology

The research question guides the researcher's interest in the scope of the research to answer the question formulated (Cifuentes, 2018) about in which cases the fourth industrial revolution in women closed the gender gap? This question allows giving a value judgment on the effects of the fourth industrial revolution on the gender gap.

The research question is related to measurement it will be aligned with a positivist research method, which seeks to provide a causal explanation of the phenomenon studied. The methods related to positivist methods can be experimental and non-experimental (Cifuentes, 2018). Since the phenomenon studied is the gender gap, a measurement that occurs naturally, given that there is no control over these variables, therefore a non-experimental design is used (Sanchez, 2023; Sánchez-Gómez, 2023).

The causal case study is a non-experimental positivist method, that seeks to identify trends and causal relationships (Beach & Pedersen, 2016), to take the case as an instance in which there is a process that relates a house to an outcome.

# 3 Results

Recent research indicates that including youth and women in fields such as engineering can significantly improve a country's Gross Domestic Product (GDP). However, to realize this potential, it is crucial to address the systemic barriers they face in accessing education and technical training in rural areas. Investing in education programs, vocational training, and digital literacy initiatives can equip them with the necessary skills and competencies to actively participate in the digital economy.

The results were classified into 4 cases that show the closing of the gender gap in the fourth Industrial Revolution. The Cátedra Matilda represents the macro context of the most important engineering associations as LACCEI in Latin America and the Caribbean region, CONFEDI in Argentina, and ACOFI in Colombia. In the Colombian context are Mujeres en la Ciencia (Women in Science) of Sciences Ministery in Colombia, UNLab 4.0 (Laboratory of Industry 4.0) of Universidad Nacional, and Ingeniosas (Ingenious Women) of Universidad de los Andes.

## 3.1 Cátedra Matilda from ACOFI, CONFEDI y LACCEI

The main objective of the Matilda and Women in Engineering Latin American Open Chair is to encourage young women to pursue careers in engineering, believing in the professional and personal development and happiness of women in this field. It is an inspiring initiative that seeks to promote equal opportunities in the field of engineering (Páez Pino, 2020).

The Latin American Open Chair Matilda and Women in Engineering was founded by the Federal Council of Engineering Deans of Argentina (CONFEDI), the Colombian Association of Engineering Schools (ACOFI), and the Latin American and Caribbean Consortium of Engineering Institutions (LACCEI). These institutions joined forces to encourage young women to pursue careers in engineering, seeking to promote equal rights, opportunities, and spaces for women in this field. A significant collaboration to boost the professional development of women in engineering in Latin America (Páez Pino, 2020).

The objectives of the CAL Matilda are:

- Promote spaces for reflection and meetings around engineering to awaken interest in engineering careers as a profession.
- Strengthen the empowerment of girls and young women, recognizing and promoting the necessary skills for the exercise of engineering careers.
- Share knowledge and practices of the engineering profession to inspire young people in the career selection stage.

- Establish a language conducive to communicating the experiences of students or recent graduates in engineering careers, motivating curiosity for the field.
- Provide mentoring and supportive accompaniment to students at any school, work, or business level to reduce the gender gap in the personal, school, and work environment.

## 3.2 Mujeres en la Ciencia of Science Ministery in Colombia

This project, promoted by the Ministry of Science, Technology, and Innovation, seeks to promote the participation of women in the scientific and technological field, offering scholarships, training, and research opportunities for young women and professionals in STEM areas (Science, Technology, Engineering, and Mathematics). The program has contributed to reducing the gender gap in the scientific sector and empowering female talent in research and innovation in Colombia.

These are just some examples of the projects and programs that are being carried out in Colombia to promote gender equity and advance the fulfillment of the SDGs. Despite the progress made, much remains to be done to close the gender gap and ensure equal opportunities for all women in the country.

## 3.3 UNLab 4.0 of Universidad Nacional in Colombia

The UNLab 4.0 initiative, developed by the Faculty of Engineering at the National University of Colombia in collaboration with private sector companies, was launched in 2021 to foster an interest in engineering among youth, especially women, in rural areas of the country. The program sought to overcome entrenched prejudices and existing paradigms surrounding STEM careers to affect a cultural shift, implementing diploma and course offerings in territorial laboratories with a clear focus on innovation and 4.0 technologies to address local issues (López et al., n.d.).

The rural Colombian context presents particular challenges in terms of access to higher education and social pressure that perpetuates gender stereotypes regarding STEM careers. The UNLab 4.0 initiative emerged as an innovative response to address these barriers and promote equal opportunities in education in areas lacking public universities. The program was implemented nationally, selecting various municipalities in Colombia such as Puerto Wilches, Villavicencio, and Tauramena, and was based on active collaboration with private sector companies. Participants, mostly women, were engaged in specific diploma and course offerings designed to foster interest and participation in STEM disciplines.

The case highlights the participation of over 6,000 beneficiaries in diverse municipalities across Colombia. Notably, 70% of these youth currently hold an academic certificate from UNAL, and 65% of participants are women, challenging the traditional perception that engineering careers are exclusively male-dominated in these rural communities. A specific data point indicating that 30% of participants became interested in studying engineering after their program participation reflects a tangible impact. Furthermore, UNLab 4.0 support in university applications has led to at least ten women initiating their engineering studies in Bogotá, Bucaramanga, or Yopal.

The program has not only provided academic certifications to these youth but also changed attitudes and perspectives in a region where forming a family used to be the primary aspiration for many women after completing high school. The initiative has confronted entrenched social pressure and gender stereotypes, challenging the notion that engineering is a profession exclusively for men in these areas (López et al., n.d.).

## 3.4 Ingeniosas of Universidad de los Andes

This program seeks to encourage the participation of women in the field of engineering through academic activities, workshops, mentoring, and networking events. Since its implementation, the program has succeeded in increasing the enrollment of women in engineering programs and improving female graduation rates at Universidad de los Andes (Cajiao et al., 2021).

The articulation between schools and universities is crucial to fostering the motivation of students in STEM careers for several reasons: identification of motivations, generation of impact, inspiration through role models, and strengthening of interests. This collaboration makes it possible to identify students' motivations when choosing a career path, which helps to design effective strategies to foster their interest in STEM. Collaborative engineering projects between high school and university students can have a positive impact on communities, motivating young people to see how their actions can improve the quality of people's lives. The ability for both girls and boys to be inspired by female engineers and scientists as role models can help break down gender stereotypes and motivate more students to pursue careers in science and engineering. Interacting with truthful information about engineering projects developed by peers in collaboration with universities can strengthen students' interests in STEM disciplines and show them the multidimensional impact they can have on their communities.

Engineering projects undertaken by high school students can have a positive impact on their communities in a variety of ways: solving local issues, raising awareness and changing behavior, generating intergenerational collaboration, empowerment, and skills development. These projects can address specific community issues, such as solid waste management, water management, and pollution, among others, offering innovative and sustainable solutions. By working on engineering projects, students can raise awareness about important issues, such as efficient water use or the importance of sustainability, which can lead to behavioral change in the community. Collaboration between high school and university students, as well as with companies and public entities, promotes intergenerational teamwork that enriches the proposed solutions and strengthens the impact of the projects in the community. By participating in engineering projects, students acquire technical, teamwork, problem-solving, and leadership skills, which contribute to their empowerment and personal development.

Finally, to inspire girls and boys to pursue careers in science and engineering, figures and role models of outstanding female engineers and scientists in the field are being used. Some strategies include Tesos Club, visibility of female roles in STEM, and role models. A Tesos Club has been created to highlight historical and iconic characters who have made important contributions to their disciplines, including women such as Lady Ada Lovelace, Hedy Lamarr, and other relevant female figures in science and engineering. The aim is to make visible and highlight the role of women in STEM through projects and activities that highlight their contributions and achievements in fields such as science and technology, to motivate new generations, especially girls, to pursue careers in these areas. The identification of female role models in science and engineering has been recognized as a fundamental strategy to guide and support girls on their path to academic and professional fulfillment in STEM (Cajiao et al., 2021).

# 4 Conclusions

The articulation between schools and universities is fundamental to motivating students to pursue STEM careers by identifying motivations, generating positive impact, inspiring through role models, and strengthening young people's interests in these disciplines. Engineering projects undertaken by college students can positively impact their communities by providing solutions to local issues, generating awareness and behavioral change, promoting intergenerational collaboration, and fostering empowerment and skill development in participants. These initiatives seek to break down gender stereotypes, inspire new generations, and show the diversity of roles and possibilities that exist for women in fields such as science and engineering, thus promoting equal gender participation in these areas.

These initiatives seek to encourage young women to pursue engineering careers and promote equal opportunities in this field. Through programs, projects, and concrete actions, we seek to empower women in engineering, generate spaces for reflection, promote interest in engineering careers, and provide mentoring to reduce the gender gap.

Innovation is essential to address complex problems in the fourth industrial revolution, and this requires constant unlearning and relearning, questioning previous knowledge, and generating new solutions. Breaking paradigms and fostering critical thinking are key aspects of broadening perspectives and possibilities for action in personal and professional life, as well as in interactions with the environment. The development of skills such as critical thinking, creativity, communication skills, and collaborative work are fundamental to facing challenges in a context of constant change and technological evolution. The use of intellectually rigorous language and the elimination of double standards are tools for questioning and overcoming prejudices, structural values, and social norms that can limit the ability to innovate and solve problems effectively.

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# Trends of educational innovation in the higher education of Latin America

Juan Sebastián Sánchez-Gómez[1], María Catalina Ramirez Cajiao[1], Karolayn Andrea Posada Casadiego[2]

[1] Universidad de Los Andes.
[2] Universidad Católica de Colombia.

Email: js.sanchez14@uniandes.edu.co

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**Abstract**

Latin America has made progress in meeting Sustainable Development Goal (SDG) 4 on quality education; however, only six countries in the region met SDG 4 by 2022. The fulfillment of SDG 4 implies improving access and quality indicators at different educational levels in each country, so it is expected that the country that meets it will present high levels of educational innovation. However, not all educational changes represent educational innovations, so a literature review was conducted to delimit the meaning of educational innovation in Latin America. The Systematic Literature Review (SLR) asked the research question What is known about educational innovation in Latin America? The SLR protocol includes three phases: plan, review, and report the results of 51 selected papers. The obtained definition of educational innovation was as a transformation that requires reflection on the feasibility and relevance of the change, which could satisfy the needs identified before the introduction of the change and imply leaving the comfort zone, thus requiring continuous learning. The results made it possible to delimit the meaning, benefits, and different approaches to educational innovations, and to understand the role of the teacher as an agent promoting change in their teaching practices and the student's learning experience.

**Keywords**: Educational Innovation; Access to education; SDG 4; Education; Latin America.

## 1 Introduction

The SDG Index of the Center for Sustainable Development Goals for Latin America and the Caribbean (CODS) measures compliance with the 2030 Agenda for Sustainable Development in the Latin American region, following the Sustainable Development Solutions Network methodology (UNSDSN, n.d.), validated by the European Commission (Sachs et al., 2019).

Since 2015, Latin America has shown more lags than goals met in the 17 Sustainable Development Goals (SDGs). Most countries in the region have not met SDG 4 on quality education, which is measured through five indicators that evaluate access to all levels of education in each country. The five indicators are the average net enrollment rate in primary education, the lower secondary school completion rate, the literacy rate for both sexes aged 15-24, the gross enrollment rate in tertiary education, and the gross enrollment rate in preschool education. (Sánchez-Gómez, 2023).

However, SDG 4 continues to lag at the regional level, reaching a score of 55.33 in 2022, below 58.65, which is the average score of all 17 SDGs in the region. Therefore, only 6 Latin American countries have achieved SDG 4, such as Argentina, Chile, Costa Rica, Mexico, Peru, and Uruguay, while the other countries in the region are lagging.

In this context, education requires that the different actors in the sector be agents of change, through the development of educational innovations that improve quality. In this task, teachers are expected to take the lead in these educational innovations. Still, it is also expected that to improve the quality of education, teachers should be well-trained.

For this reason, teacher training becomes the starting point for the design, implementation, and evaluation of educational innovations, since good training in research and innovation allows the development of relevant and sustainable innovations over time.

A systematic literature review was conducted to delimit the definition of educational innovation in Latin America, to understand its transformative meaning not only in the teaching role but also in the learning experience of students.

# 2 Methodology

A systematic literature review was used to identify and assess the validity of important studies that answer the research question (Brettle, 2003), Therefore, this study seeks to answer the question of what is known about educational innovation in Latin America. In this sense, the review aims to summarize relevant information on educational innovation as the topic of interest of this research (Cruz-Lemus, 2014). A selection of documents from different sources of information was included, including papers from indexed journals and conference papers. The review was carried out through three phases: plan, review, and report, following the methodology of (Kitchenham et al., 2007).

## 2.1 Planning

The first planning phase seeks to identify the needs of the review, formulate the research question, and define the review protocol. The review's objective was to identify the different definitions given to the concept of educational innovation in the literature, which is why we formulated the question: What is known about educational innovation in Latin America?

The literature review protocol involves defining search and evaluation criteria to limit the scope of the review to select the documents that best answer the research question.

The search criteria (see Table 1) allowed us to define the inclusion parameters at the time of the search in different sources of information.

Table 1. Search criteria.

| Criteria | Description |
|---|---|
| Language | Spanish and English. |
| Publication year | From 1995. |
| Keywords | Innovación educativa, educational innovation. |
| Type of papers | Refereed papers, conference papers, and books. |
| Databases consulted | Google Scholar, Springer, Scielo, Taylor & Francis Online, Elsevier, Redalyc y Dialnet. |

The evaluation criteria (see Table 2) made it possible to analyze the importance of the documents according to their level of contribution. The prestige criteria are related to the h-index of the author and journal, like 1 point for an h-index between 10 and 29 and 2 points for an h-index upper to 30. The abstract was evaluated in terms of clarity of the problem and the solution proposed and their pertinence for this study. The method was evaluated as 2 points for papers with aligned research questions, approach, and methods, and 1 point for papers without these consistencies. The results were evaluated as 2 points for the paper with obtained data and information related to each research question, objectives, and methods, and 1 point for papers without these coherencies.

Therefore, each document found was analyzed with the five evaluation criteria, assigning a value from 0 to 2 points for each criterion, with 0 points for low-contribution documents, 1 point for medium-contribution documents, and 2 points for high-contribution documents.

Table 2. Evaluation criteria.

| **Criteria** | **Contribution** | **Description** |
|---|---|---|
| Journal/Editorial | 0-2 points | Prestige of the journal/editorial. |
| Authors | 0-2 points | Prestige of the authors. |
| Consistency | 0-2 points | Consistency of abstract. |
| Method | 0-2 points | Methodological design |
| Results | 0-2 points | Relevance of the results. |
| TOTAL | 10 points | |

## 2.2 Review

In the review phase, the protocol designed in the previous phases is implemented, thus, the relevant documents found in the literature are obtained. First, 51 relevant documents were identified in the seven databases consulted: Google Scholar, Springer, Scielo, Taylor & Francis Online, Elsevier, Redalyc, and Dialnet.

To evaluate the level of contribution of each document, the contribution value assigned to each criterion (journal, author, coherence, appropriateness, and results) was summed, totaling a maximum of 10 points.

Each document was given a final score according to its low, medium, or high level of contribution (see Table 3). From the total of 51 documents, 21 were selected with a high contribution level obtaining a final score of 9 to 10 points, 16 documents with medium contribution obtaining a score of 7 to 8 points, 5 documents with low contribution obtaining a score of 4 to 6 points) and 9 documents were discarded for obtaining a very low score of 0 to 3 points.

Table 3. Documents by contribution level.

| **Contribution** | **Quantity** | **Percentage** |
|---|---|---|
| Discarded | 9 | 18% |
| Low | 5 | 10% |
| Medium | 16 | 31% |
| High | 21 | 41% |
| TOTAL | 51 | 100% |

Given that it is necessary to define a definition of educational innovation, which should synthesize the most important definitions in the literature, only documents with a high level of contribution were selected, i.e., those documents that obtained a final score of 9 or more points.

These 21 selected documents (see Table 4) were mostly refereed papers (76%), followed by conference papers (15%) and books (10%).

Table 4. Selected documents.

| Type | Quantity | Percentage |
|---|---|---|
| Refereed papers | 16 | 76% |
| Conference papers | 3 | 15% |
| Books | 2 | 10% |
| TOTAL | 21 | 100% |

## 2.3 Report

To identify the gaps in the literature, the proposed research question was answered by extracting the relevant data from the 21 selected documents to synthesize different ideas that made it possible to delimit the concept of educational innovation.

A thematic analysis was made of the main ideas of the 21 selected documents, which allowed the classification of these ideas into major themes. These major themes shape the trends in the literature, revealing the possible gaps in the literature on these topics.

# 3 Results

The results of this literature review allowed us to obtain a delimited definition, and understand its benefits and approaches to educational innovation.

## 3.1 Delimited definition of educational innovation

Several elements can be summarized from the above definitions. First, an educational innovation is a transformation that requires reflection on the feasibility and relevance of the change. Second, an educational innovation could satisfy the needs that were identified before the introduction of the change. Thirdly, an educational innovation implies leaving the comfort zone, thus requiring continuous learning.

However, to identify whether educational innovation is promoted in high-quality accreditation, the definition needs to be further refined. In this regard, according to (Navarro, 2000) innovation should be understood as a deliberate action with a prior planning of its objectives, a planned change that is neither spontaneous nor free, and it requires inquiring into its effects, impact, and appropriation in the educational community.

## 3.2 Benefits of an educational innovation

Understanding an educational innovation as a change allows generating opportunities for transformation in the educational sector, focused on improving the quality of the educational service. However, to improve the quality of education, good teacher training is required, through training in research and evaluation of educational innovations, promoting educational change through these innovations (Cifuentes, 2018).

In addition, an educational innovation makes it possible to ensure the rational use of ICTs for teaching (Bates, 2015) in engineering (Galvis et al., 2019), according to the learning styles (Entwistle, 2001) and reflection as a teaching and learning method (Durgahee, 1998).

Likewise, an educational innovation makes it possible to take advantage of face-to-face and virtual education modalities in a hybrid modality (Garrison & Kanuka, 2004), use of autonomous time and classroom time through the flipped classroom (Baytiyeh & Naja, 2017).

Finally, educational innovations promote the use of active methodologies in interactive classes with large groups and learning at any time and place (Salinas Ibáñez, 2003).

### 3.3 Approaches of Educational Innovation

An educational innovation can be understood from three approaches: as a change, as the introduction of a new element, or as a learning process (Cifuentes, 2018).

The first approach describes educational innovation as a change involving a transformation (Hargreaves, 2002), i.e., a change in conceptions, practices, and resources (Salinas, 2004). The change brought about by educational innovation (Fullan, 2002), is planned and guided toward improvement (Navarro, 2000), that meets the specific needs of the educational context.

The second approach refers to an educational innovation as something new, i.e., the introduction of a new product or process (Renzulli, 2003). The novelty of the educational innovation depends on the reference that exists in the educational context in which it is intended to be implemented. The introduction of this novelty can be external or internal, depending on the agent that proposes the introduction of the change (Navarro, 2000).

The third approach presents educational innovation as a learning process, which implies leaving the "comfort zone" and control. This learning consists of experiencing innovation as an unstable and uncertain process, which can be learned by observing and reflecting on the educational context in which it takes place (Kolb, 2014).

## 4 Conclusions

The literature review protocol made it possible to follow each of the phases of the process step by step. However, the protocol should continue to be validated, to continue replicating it in future research, especially those that do not have a geographical delimitation, as in this case it was done with the Latin American region. This region was selected due to the strong influence and dominance of research from the Global North, which does not allow us to know the positions and trends in the Latin American region. For this reason, special relevance was given to those documents whose authors and objects of study were related to Latin America.

The results showed that the trends of educational innovation in Latin America are related to its conceptualization, its potential benefits in different case studies, as well as theoretical discussions regarding the different approaches that educational innovations can take. However, there are gaps regarding methodological designs, methods, and good practices to successfully develop an educational innovation.

Finally, this literature review contributes to the meeting of SDG 4 for clarities about the meaning of educational innovation and to promote their design and implementation in different educational contexts in Latin America. SDG 4 seeks to guarantee access to quality education, but this quality requires best teaching practices and their continued improvement through educational innovations (Sánchez-Gómez, 2024).

In future work, it is expected to focus the literature review on the methodological aspects, to fill these gaps in the literature and provide guidelines and tools for teachers to validate these instruments, through the development of educational innovations that transform their teaching practices.

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# From Passive Learners to Active Participants: Empowering Engineering Students through Experiential Learning

Anabela C. Alves[1], Filipe Alvelos[1], Celina P. Leão[1]

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

Email: anabela@dps.uminho.pt, falvelos@dps.uminho.pt, cpl@dps.uminho.pt

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**Abstract**

Engineering students play a crucial role as agents of innovation and technological advancement, influencing technology's development and its impact on society. To effectively prepare them for this pivotal role, it is imperative to cultivate a strong sense of responsibility and autonomy in their professional development. However, achieving this in traditional classroom settings can be challenging and may stifle their ability to engage with societal issues actively. Passive learning environments risk relegating students to passive participants in social progress. Traditional problem-solving methods must be improved in the face of global challenges such as pandemics, conflicts, and environmental crises. Recognizing this, the Seminars course in the Master of Industrial Engineering and Management (MIEM), second year, first semester, introduced a novel challenge: in teams, to organize an event (e.g., roundtable, training, company visit, among others) exploring an IEM topic. This paper describes the implementation of this challenge. Teams were tasked with planning and running events within the scheduled lecture times. Eight teams, each consisting of five to seven members, enthusiastically accepted the challenge and covered various topics in their events. Event evaluation was multi-criteria, with teams judging each other's events against pre-defined metrics. Overall, student performance was commendable, and participants expressed satisfaction and pride in their achievements. Feedback gathered through end-of-term questionnaires (with a 68% response rate) revealed a high level of appreciation for the autonomy and creativity that the challenge provided. However, there is a notable concern regarding attendance at peer-organized events, with over 50% of students attending all events. This discrepancy between students' desire for meaningful education and their participation in co-curricular activities suggests a missed opportunity for impactful learning experiences. Addressing this gap could increase student engagement and foster a deeper understanding of societal issues within the educational context.

**Keywords**: Active Learning; Experiential Learning; Transformative Learning; Industrial Engineering and Management Education.

## 1 Introduction

The ongoing discussion on integrating Artificial Intelligence (AI) in education is crucial (Majeed & Hwang, 2024; Rahayu, 2023). However, equality is vital for Higher Education Institutions (HEIs), particularly Engineering Schools, to prepare the future engineering workforce for an unpredictable work environment, with or without AI assistance. In this context, the role of active learning methodologies becomes even more significant. It is widely accepted that while teachers can impart knowledge, students genuinely learn when actively engaging in the learning process. This means that students must be involved in their learning. Otherwise, learning will not occur, placing additional demands on teachers, who must strive to be innovators.

In addition, students' behaviour must change from passive learners to active participants. By doing this, they can pull what they want to learn, and they will be developing skills recognized by world organizations (World Economic Forum, 2015, 2018, 2022; World Manufacturing Forum, 2019) as fundamental to help students use technologies properly. These are: 1) creative problem-solving; 2) entrepreneurial mindset; 3) intercultural and disciplinary inclusive and diversity-oriented mindset, 4) ability to handle increasing complexity, 5) effective communication skills, and 6) open-mindedness towards constant change.

Similar skills (e.g., critical thinking, problem-solving, teamwork, communication and negotiation skills, analytical skills, creativity, and intercultural skills) are embedded in the key competences defined by the Council of the

European Union (Council of the European Union, 2018). According to this Council, the eight key competencies for lifelong learning are: 1) Literacy; 2) Multilingual; 3) Mathematical, science, technology, and engineering; 4) Digital; 5) Personal, Social, and Learning to Learn; 6) Citizenship; 7) Entrepreneurship and; 8) Cultural awareness and expression (Council of the European Union, 2018, p. 15). The fifth (Personal, Social, and Learning to Learn) key competence was the base for a European Framework called LifeComp (Sala et al., 2020). All competencies and skills are equally important; each contributes to a successful societal life.

To achieve this, students need an educational environment suitable for this development. An environment that promotes the freedom for the learner to become a connector, creator, and constructivist, as advocated by Education 3.0 (Gerstein, 2013). Students also need to be innovators and agents of their learning as education evolves through Education 4.0 (Chea & Huan, 2019; Costan et al., 2021; González-Pérez & Ramírez-Montoya, 2022; Gowripeddi et al., 2021; Miranda et al., 2021) and Education 5.0 (Alharbi, 2023; Dervojeda, 2021). Active learning methodologies, which put students at the centre of the learning process, provide the environment for this development. These methodologies have been proven to be highly effective in fostering student engagement and learning outcomes (Alves et al., 2018, 2022; Bonwell & Eison, 1991; Dewey, 1916; Felder & Brent, 2006; Felder et al., 2000; Kang, 2019; Prince, 2004).

This paper is grounded in the context of the Seminars in Industrial Engineering and Management (SIEM), the academic year of 2023_24. In this setting, the authors of this paper embarked on a paradigm shift. Instead of the traditional approach where teachers prepare the seminar class for the students, the students take the lead in preparing the seminar class for the teachers. The idea was to empower the students to pull the topics that interested them the most. This approach facilitated the development of the competencies and skills mentioned earlier. The paper's objective is to detail this experiential learning, its setup, and the students' feedback on it.

This paper is organized into six sections. The first section introduces the context and objectives of the paper. Section 2 provides a brief background on transformative learning. Section 3 presents the materials and methods used to assess the students and collect feedback. The fourth section offers an overview of the IEM Master program, with a detailed description of the Seminars in the IEM course. Section 5 presents the students' results and feedback regarding this activity. Finally, the last section draws conclusions based on the findings.

## 2 Background

Engineering Education is always a topic of interest. Despite all the changes that new technologies (e.g., AI, Virtual/Augmented reality) or new learning methodologies bring to it, there are fundamental principles that always remain the same as they are crucial to address the specific needs of engineers' future professionals. According to King (2012), these are: 1) more understanding of the human condition, cultures, and society; 2) an ability to work effectively with public policy, business, and government; 3) an understanding of the process of innovation and factors contributing toward it; 4) an ability to work in synergy with persons from other disciplines, including both other science and engineering fields and non-science/engineering fields, such as business, law, economics, public policy, political science, and sociology; 5) an ability to communicate and to express technical issues in simple, understandable terms; and 6) general liberal education integrated with engineering education.

From the earliest reports and surveys (ASCE, 2009; ASME Board of Education, 2012; Duderstadt, 2008; National Academy of Engineering, 2012; UNESCO, 2005, 2010, 2014; World Economic Forum, 2015) to the most recent ones (UNESCO, 2021; World Economic Forum, 2022; World Manufacturing Forum, 2019; World Manufacturing Foundation, 2022) all are aligned in the key competences needed for engineering workforce of future. At the same time, these reports appeal to more effective learning methodologies based on active, hands-on, experiential learning, among others. These have been used by many teachers (Alves et al., 2017; Alves, 2018; Alves et al., 2022; Alves & Soares, 2020; Bonwell & Eison, 1991; R. Felder & Brent, 2001; Gibbs & Habeshaw, 1992; Lima et al., 2007, 2017; Oliveira et al., 2020; Soares & Alves, 2021a).

Using such methodologies, students will benefit and truly transform through a meaningful learning experience and a transformative learning environment, allowing them to develop autonomous thinking (Cate & Heer, 2018; Mezirow, 1997). In this environment, teachers become facilitators and provocateurs rather than authorities (Zhang et al., 2008). The teacher's role is to help students encouragement to create norms for better organization, order, justice, and civility in the classroom, to respect and be responsible for helping each other to learn, to welcome diversity, to foster peer collaboration and equal opportunity for participation (Danila, 2018; Mezirow, 1997). Also, teachers should engage students, assigning them the responsibility to assume a more active role in their learning with their peers and in collaboration networks (Alharbi, 2023; Dervojeda, 2021; Zhang et al., 2008). Transformative learning is the essence of adult education (Knowles, 1980; Mezirow, 1997; Misawa & McClain, 2019).

# 3 Materials and methods

The research strategy employed was a case study focusing on cohort 2023_24 of 52 students in the first semester of the second year of the IEM Master program. This cohort was chosen for its relevance to the study's objectives, which aimed to assess the outcomes of the Seminar of Industrial Engineering and Management (SIEM) course activities. Furthermore, when the semester concluded, a designed online questionnaire evaluated the key competencies developed through this activity. This instrument, presented in Appendix A, was used to gather student feedback and record their observations. Titled: "Autonomy and motivation in the organization of an event at the Industrial Engineering and Management Seminar", the questionnaire comprised 35 items: 31 closed items and four open-ended items. The closed items were scored on a Likert scale [1: Totally disagree to 5: Totally agree], and one was a checkbox question (Q15).

The questionnaire was divided into six sections, each containing a variable number of items (Appendix A). This questionnaire was adapted from a previous one used for other pedagogical activities (Alves & Soares, 2020; Soares & Alves, 2021a, 2021b). The sections' categories were inspired by the skills embedded in the eight key competences proposed by the Council Recommendation on Key Competences for Lifelong Learning (Council of the European Union, 2018), as referred to in section I. For example, question 1 of section II of the questionnaire was related to the student's attitude when they read the task statement, i.e., if they got curious about that and looked for material for its execution. This attitude reveals pro-activity and problem-solving skills embedded in literacy and entrepreneurship competencies.

Thirty-two filled questionnaires were collected, representing a response rate of 62%. In this specific study case, a response rate of 62% is considered suitable for statistical analysis, as it closely corresponds to the proportion of students actively engaging in peer activities throughout the class duration, thereby supporting the validity of our research.

Besides the descriptive analysis of the collected data, hierarchical clustering was selected for the statistical analysis due to its ability to identify natural groupings within a dataset based on similarity measures, uncover underlying patterns and structures within the data, and allow the exploration of the relationships between different questionnaire items. Also, a thematic analysis of the students' answers to the open-ended questions of the questionnaire was performed to gain insights into students' perceptions and experiences related to the seminars' activities development.

# 4 Study context

This section presents the context of the Industrial Engineering and Management Master (IEM) considered in this paper. Two years ago, this master's degree underwent a curricular restructuring and is now divided into a three-year Bachelor's program (first-cycle) and a two-year master's program (second-cycle). It is part of the curriculum offered by the Department of Production and Systems of the School of Engineering of the University of Minho. This second-cycle master's program comprises 120 European Credit Transfer Systems (ECTS). The first semester of the second year comprises six courses, each worth five ECTS, with Seminars in Industrial Engineering and Management (SEIM) being one of them. The second year includes a Master's dissertation worth 30 ECTS, typically developed within an industrial context. The Seminars in Industrial Engineering and Management course, along with its structure and setup, is described in the following sections.

## 4.1 Seminars in Industrial Engineering and Management

The objectives of the SIEM course were described in the educational offer of the University of Minho website (UMinho, 2024) as *"Seminars focused on advanced engineering subjects with the participation of invited speakers. This course aims to provide students with the acquisition of knowledge and skills within the different seminars that will be organized on the topics addressed. The topics covered will focus on advanced engineering topics."*. It is expected to be 95 hours of autonomous work and 45 hours of classes in a semester that starts in September and finishes in January.

## 4.2 Organization and setting up the activity

After the activity and its purpose were introduced to the students in the first class, students organized themselves into teams: five teams of seven members, two teams with six members, and one with five members, for a total of 52 students. Teams were invited to add their team constitutions to a Padlet created for this course, which is in Figure 1.

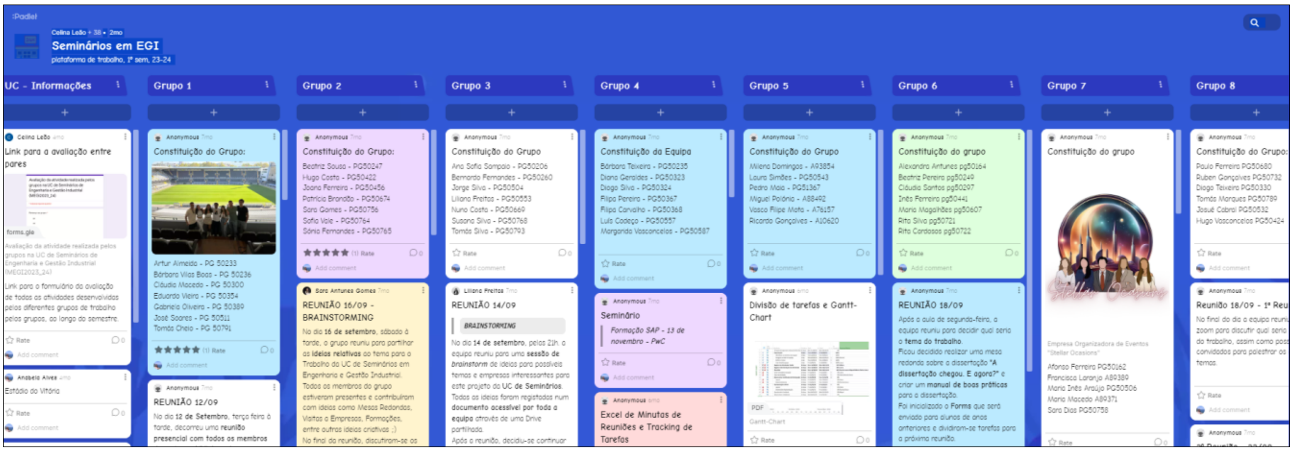



Figure 1. Padlet extract with teams formed for the course SEIM (in Portuguese)

The responsible for the SEIM course created a written document with the assignment instructions and assessment methods and shared an Excel in Google Drive for the teams to add the theme and date (week) preferred. The activities organized by the teams started in the fourth week to give them time to prepare the activity. In each session, each team approached a different topic related to Industrial Engineering and Management using a different mode to introduce the activity and identify the invited speaker(s), as described in Table 1 in more detail.

Table 1. Topics approached by the teams in each session.

| Date | Team nr. | Description | Speakers |
|---|---|---|---|
| 2023/10/02 | Team 6 | Roundtable related with the master dissertation, in Portuguese the team called "A dissertação chegou. E agora? | IEM Alumni |
| 2023/10/23 | Team 5 | Talk related with EIM and the future challenges: "O papel da Engenharia Industrial & Os desafios para o futuro." | IEM Alumni |
| 2023/10/30 | Team 8 | Roundtable related with leadership and team management: "Liderança e Gestão de Equipa". | IEM Alumni and others speakers |
| 2023/11/06 | Team 7 | Talk and Workshop about the importance of an efficient logistic: "Importância de uma logística eficiente na gestão das organizações". Then the team organized a game to play in practice layout and logistic concepts. | IEM Alumni and other speaker |
| 2023/11/13 | Team 4 | Training session about SAP system | PwC coworkers |
| 2023/11/16 | Team 3 | Company visit | Company coworkers |
| 2023/11/27 | Team 2 | Escape EGI Game and a Talk | CEO of a company |
| 2023/12/04 | Team 1 | Stadium visit (Vitória Sport Clube), talk, case study resolution about role of IEM in sport: "O papel de EGI no desporto" and discussion about the people flow in games days and impact in safety. Then, the team invited two singers to animate the visit. | Safety Director |

This activity assessment involved different criteria with different weights, represented in

Table 2.

Table 2. Assessment criteria and weight of each.

| Criteria | Weight (%) |
|---|---|
| Preparation of the activity | 20 |
| Relevance for the Industrial Engineering and Management area and creativity | 25 |
| Presentation and exposition by the speaker | 15 |
| Assessment by the other teams | 10 |
| Activity record in Padlet and report describing the activity, objectives, motivation, theme interest | 25 |
| Delivery of all materials used (e.g., flyer) | 5 |

Teams had to assess colleagues' activities using a similar criteria teachers used. For this, teachers provided them with a questionnaire using Google Forms with four main questions about the preparation of the activity (30%), relevance for the Industrial Engineering and Management area (30%), presentation and exposition of the activity by the speaker (30%), and originality and creativity (10%).

# 5 Teams achievements and feedback

This section presents the teams' achievements and discusses the questionnaire results, which fulfil the paper's main objective of understanding whether and how students perceived the development of their competences and skills towards empowerment.

## 5.1 Achievements

All teams successfully tackled the challenge with great enthusiasm. They demonstrated high levels of engagement by inviting speakers from diverse backgrounds, each addressing topics of personal interest. The extent of their involvement was evident in the multitude of elements they planned and employed to execute the activity, including attendance lists, promotional flyers, certificates, registration forms, and more. Furthermore, they planned coffee breaks and prepared tokens of appreciation for the speakers. An integral component of their promotional efforts was the creation and distribution of flyers, exemplified in Figure 2.


Figure 2. Flyers used by the eight teams (in Portuguese)

The data collected is in Table 3 and includes the number of participants, the number of answers received in the activity assessment questionnaire from the other teams, and the response rate. The response rate is obtained by dividing the number of answers by the number of participants, expressed as a percentage. Additionally, the teams utilized different elements to support the activity, such as flyers, registration forms, and certificates. The total number of different elements available for their use was 28. This value represents the various elements each team develops according to their respective activities.

Table 3. Participants, respondents, response rate and number of elements used by the teams (T1-T8).

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | Average |
|---|---|---|---|---|---|---|---|---|---|
| **Number of participants** | 15 | 32 | 23 | 41 | | 32 | 33 | 19 | 28 |
| **Number of answers** | 27 | 29 | 23 | 28 | 29 | 29 | 26 | 24 | 27 |
| **Response rate (%)** | 180 | 91 | 100 | 68 | | 91 | 79 | 126 | |
| **Number of elements used by each team** | 14 | 12 | 11 | 14 | 5 | 8 | 14 | 8 | 13 |

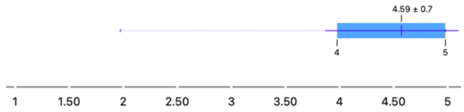
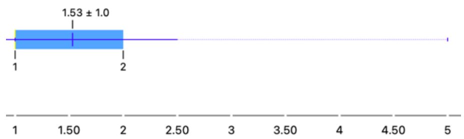
Note: Blank cells indicate that the data was not collected or could not be obtained.

Moreover, the students' teams performed well, demonstrating high levels of engagement in captivating their colleagues' interest and attention. Grades awarded to the teams ranged from 85% to 97%, based on the criteria outlined in Table 2 above. These scores slightly surpassed the evaluations they provided to other teams, which fell between 81% to 93%.

## 5.2 Analysis of questionnaire responses

Due to space limitations, this paper will primarily analyze aggregated data from the questionnaire responses, focusing on key themes aligned with the study's objectives. While the dataset includes responses to all 35 questions, individual analyses will be conducted selectively, with a preference for aggregate data representation, allowing a more comprehensive data exploration. Descriptive statistics, like the median, mean, and coefficient of variance (CV), summarize each question's responses (Table 4). With the focus on the mean, it is possible to identify questions where most students agreed or disagreed and, based on the CV value, the more consistent and varied answers. Table 4 presents the different descriptive statistics values in descending order of the mean value and the summary of the data distribution obtained in Q17 (the highest mean student's agreement) and Q28 (the lowest mean agreement).

Table 4. Descriptive statistics obtained for each question in descending order of the mean value.

| Items or questions / Section / Cluster | Statistics Metrics | | | | | |
|---|---|---|---|---|---|---|
| | Mean | CV* | Median | Min | Max | Distribution |
| Q17 / S III / C1 | 4.59 | 0.15 | 5 | 2 | 5 |   |
| Q18 / S III / C1 | 4.50 | 0.20 | 5 | 1 | 5 | |
| Q7 / S II / C1 | 4.34 | 0.16 | 4 | 3 | 5 | |
| Q6 / S II / C1 | 4.31 | 0.18 | 4.5 | 3 | 5 | |
| Q10 / S III / C1 | 4.31 | 0.12 | 4 | 3 | 5 | |
| Q8 / SII / C1 | 4.28 | 0.17 | 4 | 3 | 5 | |
| Q2 / S II / C1 | 4.25 | 0.18 | 4 | 3 | 5 | |
| Q11 / S III / C1 | 4.25 | 0.20 | 4 | 2 | 5 | |
| Q3 / S II / C1 | 4.19 | 0.23 | 4 | 1 | 5 | |
| Q20 / S IV / C1 | 4.19 | 0.24 | 5 | 2 | 5 | |
| Q30 / S IV / C3 | 4.19 | 0.19 | 4 | 2 | 5 | |
| Q12 / S III / C1 | 4.09 | 0.25 | 4 | 2 | 5 | |
| Q26 / SIV / C1 | 4.06 | 0.24 | 4 | 1 | 5 | |
| Q16 / SIII / C3 | 4.03 | 0.20 | 4 | 2 | 5 | |
| Q21 / SIV / C1 | 4.00 | 0.27 | 4 | 1 | 5 | |
| Q24 / S IV / C3 | 4.00 | 0.21 | 4 | 2 | 5 | |
| Q5 / S II / C1 | 3.97 | 0.20 | 4 | 2 | 5 | |
| Q25 / S IV / C1 | 3.88 | 0.26 | 4 | 1 | 5 | |
| Q4 / S II / C1 | 3.75 | 0.29 | 4 | 1 | 5 | |
| Q1 / S II / C1 | 3.72 | 0.24 | 4 | 1 | 5 | |
| Q13 / S III / C1 | 3.66 | 0.29 | 4 | 1 | 5 | |
| Q9 / SII / C3 | 3.59 | 0.26 | 4 | 2 | 5 | |
| Q22 / SIV /C3 | 2.87 | 0.41 | 3 | 1 | 5 | |
| Q29 / SIV / C2 | 2.81 | 0.47 | 3 | 1 | 5 | |
| Q27 / S V / C2 | 2.56 | 0.45 | 2 | 1 | 5 | |
| Q19 / S IV / C1 | 2.53 | 0.41 | 3 | 1 | 5 | |
| Q14 / S III / C3 | 2.34 | 0.47 | 2 | 1 | 5 | |
| Q23 / S IV / C2 | 1.71 | 0.61 | 1 | 1 | 5 | |
| Q28 / S V / C2 | 1.53 | 0.63 | 1 | 1 | 5 |   |

* coefficient of variation (CV) defined as the ratio of the standard deviation to the mean

The contrasting results between the item "Q17. I was able to understand with this activity that the organization of events is also a project" and "Q28. I preferred that others do the task for me" highlight interesting insights into student perceptions and attitudes towards collaborative work and project management.

The high mean score for the item regarding understanding the activity as a project suggests that students recognize event management's organizational and planning aspects. This indicates a positive outcome regarding students' awareness of project management principles and their ability to apply them in practical scenarios. It suggests that students may have gained valuable insights into project management methodologies and the complexities of organizing events. On the other hand, the low evaluation score for the item indicating a preference for others to do the task suggests a potential reluctance towards taking individual responsibility or actively participating in tasks. This may reflect a lack of engagement or motivation among some students, which could impact collaborative efforts and the overall effectiveness of group work.

Based on a hierarchical clustering for Likert scale data, the Ward linkage method is often a suitable choice due to its ability to identify clusters that minimize within-cluster variance, which aligns well with the typical characteristics of Likert scale responses (Budayan et al., 2009) Three main clusters were identified through hierarchical clustering provide valuable insights into the underlying dimensions of the constructs being measured, enabling a deeper understanding of the factors influencing student perceptions, motivations, and behaviors in the context of the activity (Figure 5).

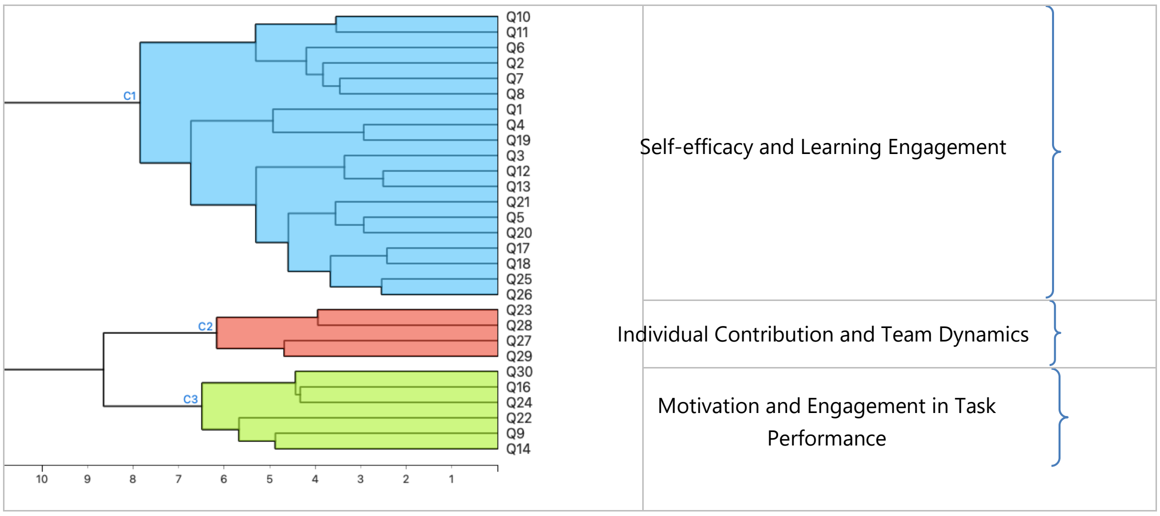



Figure 5. Three clusters identification obtained using a hierarchical clustering algorithm (the horizontal axis identify the distance at which clustering occurs).

Identifying these three clusters offers a nuanced understanding of student engagement and performance within the seminar context. The first cluster (C1) includes items related to students' self-efficacy beliefs, their level of engagement in learning activities, and their abilities in completing tasks.

Cluster C2 focuses on individual contributions within team settings and the dynamics that unfold during collaborative work. Examining responses in this cluster, which comprises items with the lowest average based on students' answers, it is essential to delve into the underlying factors contributing to these lower ratings, namely collaboratively developing strategies to enhance teamwork effectiveness and ensuring equitable participation among team members.

Cluster C3 encompasses answers related to motivation, engagement, and performance in completing tasks. This cluster sheds light on the factors that drive students' enthusiasm and commitment to the assigned tasks and their effectiveness in task completion. Communication and negotiation skills were identified as playing an important role in the development of the activities. A consensus appears between the lower mean obtained in the items from C2, which focuses on team dynamics and the concepts of communication and negotiation skills. However, the items from C2 present a higher variability, indicating a mixed perception or experiences among students regarding some aspects of teamwork. Individual preferences, communication styles, past experiences, and team composition may contribute to this variability.

Regarding the qualitative data from the open-ended questions, a qualitative analysis was performed based on word clouds generated, offering a nuanced exploration of the underlying themes and sentiments expressed by participants (Figure 6). The main words used by the students to describe what pleased them most (Figure 6a) were "diversity", "activity", "creative", "theme", and "content". "Diversity" related to the variety of topics and "content" covered, while "activity" was associated with the preparation required to complete the task successfully. Similarly, "creativity" encompassed various aspects, such as the inventive nature of activities, collaboration with colleagues, and ideas explored. Additionally, "theme" was linked to the freedom and flexibility to choose topics of interest. In summary, these words collectively express the students' appreciation for the multifaceted nature of the tasks, engaging activities, opportunities for creative expression, and autonomy in selecting themes.

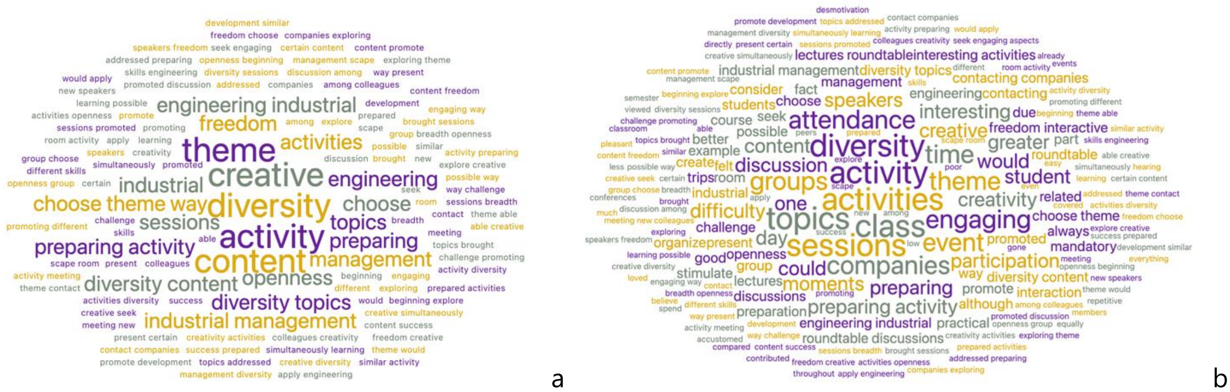



Figure 6. Word cloud generated from the open-ended questions: (a) Q31. What pleased most in this task was..., and (b) considering all four questions of section VI.

Upon analysing the responses to all four open-ended questions from the final section of the questionnaire (Q28 to Q31), it is evident that the most frequently utilized words are consistent across responses (Figure 6b). However, the term "attendance" emerges in connection with various aspects, including class schedules, duration of activities, and sentiments of demotivation and absence, indicating a lack of balance in the participation of some students during the whole semester.

## 6 Conclusions

This paper explores the answers of engineering students to a unique challenge presented in the Seminars course of the Master of Industrial Engineering and Management (MIEM) program. The challenge involved organizing events and exploring various industrial engineering and management (IEM) topics in teams as an innovative approach to fostering students' sense of responsibility, autonomy, and engagement in their professional development. Eight teams enthusiastically embraced the challenge of planning and executing diverse events (seminars, training sessions, and visits, among other activities) within the scheduled lecture times. Event evaluations were conducted using predefined metrics, reflecting the multi-criteria nature of the assessment process. Overall, student performance was commendable, with participants expressing satisfaction and pride in their accomplishments.

The findings from this study underscore the effectiveness of experiential learning approaches in cultivating essential competencies among engineering students. The high level of appreciation for the autonomy and creativity afforded by the challenge highlights the value of hands-on, project-based learning experiences in higher education. However, the notable concern regarding attendance at peer-organized events raises important considerations for enhancing student engagement and participation in co-curricular activities. Addressing this gap presents an opportunity to create more impactful learning experiences that foster a deeper understanding of societal issues and promote active engagement in addressing them. By leveraging innovative pedagogical approaches and incorporating meaningful co-curricular activities, educational institutions can better prepare engineering students to tackle real-world challenges and drive positive societal change.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## Appendix A: Questionnaire

Sections of the questionnaire and questions of each section based on Alves at al. (2022).

| Section | Items/questions |
|---|---|
| I. Introduction | ---- |
| II. Autonomy and proactivity (9) | Q1. After reading the task/work statement, get curiosity and get immediate material for execution.<br>Q2. I did extra work for this task.<br>Q3. The task offered me an initiative to learn new concepts.<br>Q4. I tried to use the materials that I find.<br>Q5. I retrieved additional information about the topics that interest me.<br>Q6. I didn't wait that the teacher and/or colleagues tell me what to do.<br>Q7. I took responsibility for my learning.<br>Q8. Although working as a team, the activity gave me the various stages of its autonomy.<br>Q9. I had other priorities besides the task. |

| | |
|---|---|
| III. Critical thinking (9) | Q10. I trusted in my abilities to learn different concepts.<br>Q11. I trusted in my ability to prioritize and show the important over the accessory.<br>Q12. The task/work allows me to understand and apply the content in new situations.<br>Q13. The task allowed me to analyse, summarize and evaluate the contents.<br>Q14. I needed more explanation from the teacher to perform this task.<br>Q15. The criteria that I considered for assessing a task are…<br>Q16. The grade obtained to the activity reflected the work performed.<br>Q17. I was able to understand with this activity that the organization of events is also a project.<br>Q18. The organization of events brings challenges that an Industrial Engineering professional must be prepared to deal with. |
| IV. Motivation and creativity (8) | Q19. The task motivated me to search for scientific articles on the subject.<br>Q20. I was pleased and proud in developing this task/job.<br>Q21. I felt that I learned more from the way this task/work was done.<br>Q22. The main reason for completing the task was to accomplish the course requirements.<br>Q23. I did the task/work to avoid the blame of not doing.<br>Q24. To have a problem to solve motivated me.<br>Q25. I enjoyed spending time learning the contents of the task.<br>Q26. The task/job stimulated my creativity. |
| V. Teamwork, communication and negotiation (5) | Q27. I completed most of my colleagues' tasks.<br>Q28. I preferred that others do the task for me.<br>Q29. There should be a peer review to distinguish the grade of this task/work from team members because not all members work with the same commitment.<br>Q30. The preparation of this activity required communication and negotiation skills.<br>Q30a. If your answer is positive, give examples. |
| VI. Open-ended questions (4) | Q31. What pleased most in this task was…<br>Q32. What pleased less in this task was…<br>Q33. what could be improved…<br>Q34. To increase the intervention of the students of other teams during the activity is important to… |

# Visual representations and learning obstacles for definite integrals in first semesters undergraduate students, a preliminary report

René E. Castillo[1], Gabriel Padilla[1]

[1] Departamento de Matemáticas, Universidad Nacional de Colombia, AK45 Cl30 Ciudad Universitaria Edif. 4040 Yu Takeuchi, Bogotá 111321 Colombia.

Email: recastillo@unal.edu.co, gipadillal@unal.edu.co

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**Abstract**

This study is the first on a sequel, and a preliminary diagnostic study in the area of Didactics of Mathematics, which aims to review the teaching strategies for the Integral Calculus course, before carrying out the subsequent pedagogical field interventions. We targeted the most difficult topics for the students and described some of the variables which are potentially engaged in the performance of students and the survival and desertion rates in the first semesters of technical careers. In sections 1 and 2 the reader will find general information, the methodology and protocol applied in this research. Sections 3, 4 and 5 are dedicated to evaluating the subjective perception of difficulty reported by students, and using this variable to determine the topics that merit direct didactic intervention in the classroom. Section 6 explains the treatment given to the control group and the experimental group, in relation to the evaluation of visual thinking and the didactic intervention applied. Sections 7 and 8 are dedicated to the discussion of the final results and conclusions.

**Keywords**: Active Learning; Riemann integral, visual representations.

## 1 Introduction

Students of Integral Calculus (IC) courses, use to present different cognitive resistances which can hinder their understanding of the notion of Riemann integrals (Tharayil, 2018). These difficulties could be related to the different visualization capacities of the students (Huang, 2015) as well as the semiotic nature (WinslØw, 2004). Our general problem is to find effective teaching strategies to address this issue, this study is a preliminary diagnostic survey on the general teaching-learning situation prior to the subsequent pedagogical interventions. We describe some of the variables which are potentially engaged in the performance of students and the survival and desertion rates, in order to provide some guidelines on the nature of the didactical work that should be done. These goals are aligned with the objectives 1, 2 and especially 4 of the UN agenda on sustainable development (ONU, 2022), so as for the local policy of the Colombian government (SPADIES,2015) and the internal UNAL policy (Pinto, 2007).

## 2 Experimental Design

### 2.1 Methodology

The protocol we chose is the design of a descriptive-analytic statistical survey, in the form of a non-simultaneous double-blind study, applied in two phases. In the first phase we constituted a sample of repeating IC students, which was refined using demographic criteria. A questionnaire was administered to the subjects in order to assess their subjective perception of the difficulty of IC topics, which was used to determine the topics that required a didactic intervention. In the second phase, a control group of repeat students was drawn from the initial sample. A sequence of didactic situations aimed at addressing the determined didactic topics was applied. In the next semester, this same sequence was applied to a new sample made up of students who were taking CI for the first time.

## 2.2 First phase sampling frame and inclusion-exclusion criteria

Through a public invitation, we contacted students who enrolled for the two upper Calculus subjects (Integral and Multivariate) in the semester 2023-2 at the UNAL. We wanted the subjects to explain their experiences with previous IC courses. We accepted all students who had completely attended the IC at least once. We excluded first time students as well as those who had dropped out.

## 2.3 Constitution of the sample

The initial group was constituted by 85 subjects who attended classes with 4 different classrooms and were chosen by simple random samplings. We applied a simple statistical study with the purpose of detecting concomitant variables. The minimum age of the subjects was 17 years, the maximum age was 47 years. The average age of the sample was 21.94 years, with a standard deviation of 5.192378 years. We asked for the biological sex of our subjects, 66 of 85 which (77.64 %) were men, 18 (21.17 %) were women, and 1 subject preferred not to declare. We asked about the name and type of institution, the faculty and the undergraduate program they had previously attended. 3 subjects in the sample (3.53 %) had previously studied in private institutions, the rest (82 in total, 96.47 %) had studied at public universities. 1 individual in the group (1.17 %) came from having previously studied in a statistics program, 8 subjects (9.41 %) came from careers in natural sciences, 4 (4.7 %) from programs in Economics, Agronomy or Social Sciences, and 2 (2.35 %) came from other programs such as Veterinary Medicine. The rest (70 individuals, 82.36 %) had studied some undergraduate engineering program. 81 individuals did not finish the program they had previously enrolled, but rather had withdrawn from the first institution in order to start again at the UNAL. Asked about the year in which they had last enrolled in the IC subject, one individual decided not to answer, it turned out to be a 22-year-old student from UNAL, we withdrew him from the sample. The rest of the subjects 'answers (83 individuals, 97.65 %) were between 2000 and the first semester of 2003, with mean $\overline{x} = 2022$ and standard deviation $s = 1.238497$. The sample was finally made up of 82 students, coming from different university institutions, public and private, with age ranges between 17 and 29 years, and had enrolled for the last time after 2017. From now, we will call this group the **triage group (TG)** of this study.

# 3 Students' Perception of Difficulty

We applied a short questionnaire to TG subjects in order to compare the student's perception of difficulty.

- Question 1. "*Please tell us how difficult each of the following topics was at the time you studied them for the first time, just as you remember and according to your perception. Use a scale from 0 to 5 where 0 represents a topic which was so easy that it did not present any difficulty for you, 3 is a topic or skill of intermediate difficulty and 5 was an issue that you considered very difficult or impossible to understand at that time*".

We made a list of about 25 topics in the IC program. The measurements varied very little between the topics belonging to the same thematic, so we chose a single representing topic for those presenting similar behaviors, these are the ones which remained clearly distinguishable. **L:** Limit definition with ε-δ formula. **LUB:** Least upper bound (LUB). **Series** (definition, examples and criteria). **RS**: Riemann sums. **RI**: Riemann integral definition. **TFC**: The fundamental theorems of Calculus. **VC**: Change of variables (solution of indefinite integrals by). **IbP**: Integration by parts. **TS**: Trigonometric substitutions. **W**: Weierstrass 'substitutions.

They were classified according to the subjective perception of their intrinsic difficulty, as: **Easy**: Those whose median is $M = 2$ and 3rd quartile $q_3 \leq 3$. Among those we have the notion of Riemann Sums, the Fundamental Theorem of Calculus and the technique of changing variables for solving an indefinite integral. **Intermediate type A**: Those for which $M = q_3 = 3$. The only item satisfying this is the topic of limits with the ε-δ definition. **Intermediate type B**: Those whose median is $M = 2$ and 3rd quartile $q_3 = 4$. Among those we have the definition of Riemann integrals and the method of integration by parts. **Intermediate to difficult**: Those with $M = 3$and $q_3 = 4$. Among those we have the definition of Least Upper Bound, the notion of Series and its examples, and the resolution of indefinite integrals by trigonometric Change of variables. **Difficult**: Those with $M = 3 = q_1$. The only item satisfying this is the topic of resolution of indefinite integrals with the Weierstrass ‘substitution.

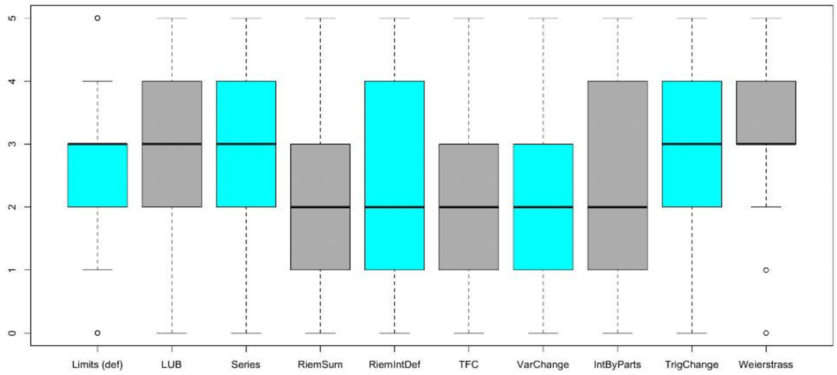


Figure 1. Box plots for answers of question 1, the topics described considered as different variables.

The difference between the intermediate classes A and B is not in the median, but in the dispersion of the data. For class A, 50  % of the data (quartiles 2 and 3) is concentrated between 2 and 3, so the perception of the students is that the topic presents an intermediate difficulty, neither very high nor very low. On the other hand, for class B the scores have been dispersed between 1 and 4, leaving the median at 2 and the mean a little above, between 2 and 3. So there is a general perception that the topic is intermediate, but there is also a larger number of subjects who think it is easy or difficult.

- Question 2, "*Among the listed topics, in you own perception, which is the most difficult?*" The choices were the same as in question 1. 2 subjects (2.44  %) answered L, 2 (2.44  %) LUB, 21 (25.61 %) S, 4 (4.88 %) RS, 7 (8.54 %) RI, 1 (1.22 %) TFC, 3 (3.67 %) VC, 2 (2.44 %) IbP, 13 (15.85 %) TS, and 4 (4.88 %) W.
- Question 3, "*Is there any topic not mentioned in the above list that, according to your appreciation, was very difficult? Which one?*" 58 of the subjects (70.73 %) answered No. The rest of the subjects mentioned many different additional topics, which were grouped in the following representative labels, **SR**:  Solids in revolution. **PF**: Partial fractions. **T**: Trigonometry (identities, angles and applications). **TP**: Trigonometric powers (indefinite integrals of). **PC**: Polar coordinates. **PS**: Power series (Convergence criteria, Taylor theorem, etc.). **App**:  Applications of definite integrals. 10 subjects (12.20 %) answered SR , 2 (2.44 %) PF, 2 (2.44 %) T, 2 (2.44 %) TP, 5 (6.1 %) PC, 2 (2.44 %) PS, and 2 (2.44 %) App.

## 4 Determination of Pertinent Topics

Assigning to each variable the sum of the correlations with respect to the other different variables in the list, we obtain function of cumulative correlations with respect to the topics ‘difficulty as perceived by students. We decided to consider this function as a measurement of the pertinence of the topics. A particular topic $X$ was considered pertinent if its cumulative correlation $f(X)$ satisfied $f(X) \geq 4$. Five topics entered this criterion: RS, RI, TFC, VC and IbP, for which respectively $f(RS)$ =4.359788, $f(RI)$ =4.384189, $f(TFC)$ =5.122916, $f(VC)$ =4.898077, and $f(IbP)$ =4.823379. Notice that the answers to questions 2 and 3 contradicted this criterion. It should now be pointed out that this survey was about the subjective perception of students. Due to the answers to questions 2 and 3, we included the topics of series (S), trigonometric substitutions (TS) and solids in revolution (SR). The list of relevant issues in the IC course, according to the student's perception of difficulty, was made up of 8 topics, namely S, RS, RI, TFC, TS, VC, IbP and SR. These are the topics we chose to target in a first intervention.

# 5 Didactical Approach on The First Encounter

We explored the information which was available to the students, with respect to the didactical approach used in their first approach of IC.

- Question 4, "*Which of these teaching tools or classroom strategies were used by your first teacher of IC?*". Student had to answer Yes or No to each item of the following, **CbH**: Calculations by hand. **P**: Plots by hand or any other means, included computer graphics such as Geogebra or Desmos. **L**: Logical proofs (such as ε-δ limit proofs by definition, or proofs by induction in N). **SV**: Semiotic-Visual diagrams, such as flowcharts, mind maps or graphical calculators. See (Alson, 1987), (Castillo et al, 2023). **NPL**: Numeric Programs or Computational Languages such as MatLab, Python, etc. 69 subjects (84.15 %) answered Yes for CbH, 59 (71.95 %) for P, 51 (62 %) for L, 22 (26.84 %) for SV and 21 (25.61 %) for NPL. The prevalent strategies for teaching IC continue to be CbH, P and L, the most used in a traditional master classes. The use of other methods was remarkably lower.
- Question 5, "*In the most difficult topic, what was the tool/strategy used by the teacher?*". The possible choices were, as in question 4, CbH for calculus by hand, P for plots, L for logic and proofs, SV for semiotic-visual, NPL for numeric or computational algorithms. 27 subjects (32.93 %) answered CbH, 3 (3.67 %) L, 1 (1.21 %) L, and 2 (2.44 %) NPL.
- Question 6, "*What was the predominant didactic approach used by the teacher with which you first saw these notions?*". The choices were **NA** No Answer, **NAp** The teacher did not have a clear didactical approach, **Pol** Polya's resolution of problems, **FC** Flipped classroom, **ST** STEAM education, **DS** Didactical situations, and **O** Other. 30 subjects (36.59 %) answered NA, 28 (34.15 %) NAp, 11 (13.41 %) Pol, 4 (4.88 %) FC, 4 (4.88 %) ST, 3 (3.67 %) DS, 2 (2.44 %) O.
- Question 7 we asked, "*On the most difficult topic, would you have preferred that the teacher used a different tool/approach*?" 33 subjects (40.24 %) answered Yes, the rest of the sample (59.76 %) answered No.

We invited the subjects of the initial sample to continue in our study. 52 subjects answered affirmatively and conformed the sample for the 2nd questionnaire. From those, three students withdrew due to different reasons. The TG was reduced to the remaining 49 volunteers.

# 6 Visual Thinking Assessment

Many sources persuaded us that our didactical intervention should involve changes in our teaching strategies (Attorps et al, 2013), (González, 2022), through the design of didactic situations (Brousseau, 2002) focused on visual thinking with logical and numerical processes (Pritchard, 2022). Others like (Godino et al, 2021), (WinslØw, 2004), have dealt with the need to identify the types of images that students use in their visualization processes. In order to measure the students 'visualization skills, we applied the instrument presented in (Huang, 2015). The original survey was administered to 15 students, chosen among the top 10 % of their pairs, which allowed the author to interview each subject individually. The place where the survey was carried on is Taiwan, whose demographic differences with respect to Colombia are evident. The results of this work can be considered, in some extent, as a standardization of Huang's test.

The visual thinking skills were categorized to 5 competencies and three levels. **NV**: Non-visual level, the students focus on a single visual image, prefer to solve problems using symbolic representations, and rely on analytical thinking instead. **LV**: Local-visual, the students can perceive relationships among various visual images, however there is a lack of coherence in the representative system. **GV**: Global-visual, the students can use the relationships to construct a consistent structure based on the relationships among various visual images. This consistency determines the scope of visual thinking. Following (Huang, 2015), the test for measuring the visual thinking was constituted by the following tasks,

(1) Given that $\int_1^3 f(t)dt = 8.6$, use two different strategies in order to evaluate $\int_2^4 f(t)dt$.

(2) The graph of a function $f$ is sketched in figure 4. Given that $\int_{-2}^5 f(t)dt = \frac{39}{8}$, determine the value of the constant $C$.

(3) Is it true or false that, if $\int_a^b f(x)dx \geq \int_a^b g(x)dx$, then $f(x) \geq g(x)$ for all $a \leq x \leq b$? Please justify your answer.

(4) If $\int_1^5 f(x)dx = 10$, use two different strategies in order to evaluate $\int_1^5 (f(x) + 2)dx = 10$.

(5) Use two different strategies in order to calculate $\int_{-3}^3 |x - 2|dx$.

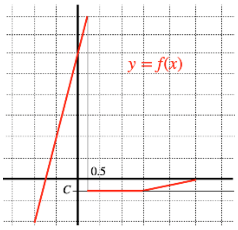


Figure 2. Curve related to question

## 6.1 Application of the survey

This study was initially applied to the reduced TG, without any previous didactical intervention. For the semester 2024I we reapplied it on two new samples: (a) A group of 33 students who were subjected to some of our didactical situations and teaching strategies, with semiotic/visual tools, before applying the study, which will be called the Experimental Group (EG). (b) A group of 20 students who followed a traditional master class course, which will be called the Control Group (CG). The study was applied to both groups as one more within the rest of the evaluations carried out, without warning them about its purpose. The responses were reviewed, focusing solely on this aspect.

For the application of the survey, we followed some criteria that varied a little from the original study. In order to perform simple statistical analysis, we assigned a numerical score to each level of visual thinking, 0 for NV, 0.5 for LV, 1 for GL. In the original study, the author interviewed each student separately. Given the size of our samples, we decided to only take written responses. We encouraged students to explain, as much as they could and in their own words, the thought process they were carrying out. We applied a correction factor to the written scores as follows: Any response alone, without a justification, was scored as 0 (NV). Any response whose wording was confusing was scored as 0 (NV). Any response in which there was no evidence of visual thinking was scored as 0 (NV). Any response in which there was evidence of visual thinking, but the representations (i) were not coherent with each other, or (ii) were not integrated into the symbolic-algebraic response; were scored 0.5 (LV). Any response in which there was evidence of several mutually coherent representations, or that were integrated into symbolic-algebraic reasoning, were scored 1 (GV).

## 6.2 Didactical intervention on the experimental group

For our didactical intervention on the EG we followed the didactical situations of (Brousseau, 2002), using the graphical calculators (Alson, 1987), these are diagrams similar to the flowcharts in computing sciences, they allow students to recognize the underlying presence of an algorithm,

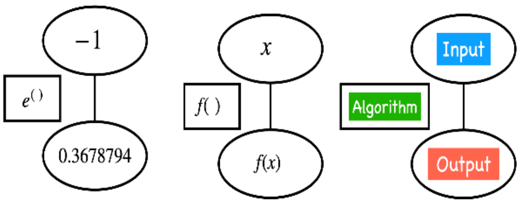


Figure 3. Alson's diagrams, called "graphical calculators".

They can also be used in order to explain the 2nd Fundamental Theorem of Calculus and illustrate antiderivatives, similar semiotic relations underlie among functions, derivatives and integrals. Our main idea was to grasp the notion of Riemann integral by organizing these sets of situations;

- Preliminary situations: arithmetic operations, the notion of area, basic instructions in R.
- Geometric/numeric situations: We treated Riemann sums from basic shapes to positive real continuous functions. The purpose is to approximate areas without knowing how to find antiderivatives. As an example, we treated the problem of measuring the area of a unit-circle. The situation develops around the approximation of the area of the circle, first with known figures (inscribed or circumscribed squares), later with rectangular subdivisions (Riemann partitions, without formalities). Using the insights and the knowledge acquired in the former basic situations, the first steps can be done with a pocket calculator. As more intermediate points are added, the approximations get narrower until, at some point, the process becomes ridiculously tedious. The teacher stops the game and asks: "*How can we do this faster?*", or "*Can we do this better with a computer?*". So we pass from calculating areas to the design of a numerical algorithm which will approximate the number $\pi$. A debate will arise about the heights of the intermediate points, the function $f(x) = \sqrt{1 - x^2}$ and its role. It is possible to talk also about approximation errors. There will appear the need of an agreement about what a "reasonable" approximation is.
- Symbolic/algorithmic situations: We dealt with basic antiderivatives which can be usually solved either by substitution, or by a simple change of variables. The student needs to recognize "someone's derivative" and apply the Fundamental Theorem of Calculus. This can also be used to construct a primitive function $F(x)$ placed at a particular point of the real line $a \in \mathbb{R}$, and whose value $F(x)$ on each $a \leq x \leq b$ is the definite integral of $f(x)$ on the subinterval $[a, x]$, which can be now calculated with similar R-codes. The numerical method does not depend on the student's ability to calculate antiderivatives. The "reasonable approximation" criterion agreed before will now be applied. Then the Riemann sum provides the equivalent of a key in a pocket calculator, and can therefore be represented with Alson's diagrams. Although the semiotic relations of its components remain, the objects in the ovals are neither numbers/constants nor letters/variables, but functions/processes. We will refer to them as 2nd level diagrams.

```
% R-code template for Riemann sums
% with a 'reasonable' approximation <10^(-6)
a=ZZZ % fill in the ZZZ with the value of extreme a
b=ZZZ % fill in the ZZZ with the value of extreme b
n= 10^6*roof(b-a)
F=function(X)(ZZZ) % fill in the ZZZ with the
% instructions for the integrand function f(x)
x=seq(a, b, by=1/n)
Int=sum(F(x))/n
Int
```

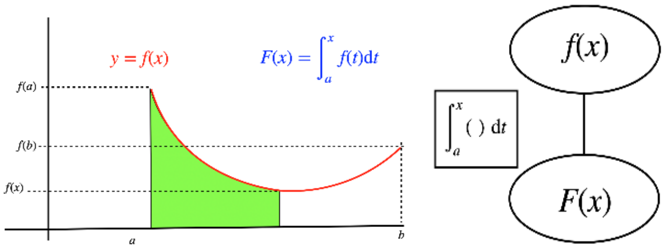


Figure 4. Construction of a 2nd level(Alson's diagram with a R-code template.

- Inter-validating situations: The Social validation of the knowings within the classroom was achieved by a series of mutual interactions between students, through the comparison of outcomes in the competitive and collaborative games proposed by each didactic situation. Fore more details, see (Castillo et al, 2021).

## 7 Results

We have remarked before the qualitative results that one can obtain by applying this sort of visual/semiotic didactical situations. **Teacher-student relationships**: The interaction with students is therefore a reconfiguration factor in the approach to obstacles and resistances, so teacher-student relationships improve when compared to the master classes. **Comprehension of the problem**: Through a progressive adidactical phase design, students in the experimental groups gain a deeper understanding of the subtle aspects of the integral. **Interactions within the classroom**: Since the truth is not based on authority, but rather in experimentation, knowledge is built as a social construction. Now we are also able to measure the effect that the application of this type of didactic situations in a field intervention has on students' visual thinking and its integration into symbolic logical thinking.

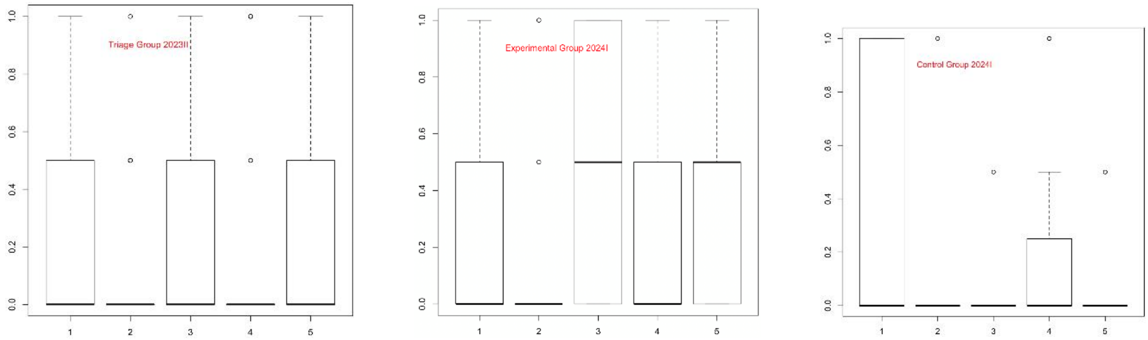


Figure 5. Visual thinking results for the three groups. Left: (TG) Triage group of repeating students. Center: (EG) Experimental group subjected to visual/semiotic didactic situations before the test. Right: (CG) Control group exposed to a traditional master class without any other didactical methodology or teaching strategy.

In figure 5 the behavior of the variables that correspond to the tasks of the Visual Thinking Test is shown separately, for each of the samples. The following common features and global differences between the three samples can be seen. Except for task 1, the group that develops greater use of visual thinking abilities in the rest of the tasks is the experimental group, in which a simple intervention was applied, made up of a battery of didactic situations that we will explain in detail in another article to appear, which were developed before the application of the study. This is followed by the triage group, which generally showed a lower use of visual thinking skills. The group with the lowest level of visual thinking is the control group. In neither of the last two groups were teaching situations used before applying the study. Our interpretation of these results is that, possibly, the students in the triage group developed some of the visualization skills on their own during the semesters in which they had to repeat the course.

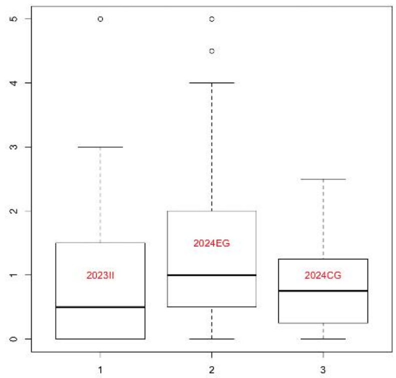


Figure 6. Visual thinking results for total score variable.

An additional variable was calculated with the sum of all visual thinking scores on each task. This total score whose value ranged between 0 and 5 points, constitutes a kind of global appreciation of the students' visual thinking. The fact that the experimental group showed a greater use of visual thinking at the global and local levels, shows to some extent the result of the didactic intervention carried out in the experimental group. The improvement in tasks 3 and 5 indicates better integration and coherence between visual representations and logical-symbolic solutions. When observing the total score variable of the levels of visual thinking, a fairly similar behavior is observed. The experimental group has a higher mean than the other two, and the dispersion of the scores is more upward, with a greater width of the range.

# 8 Final Conclusions

This work is an attempt to justify the relevance of a didactic intervention with visual-semiotic tools, aimed at processes that involve visual thinking. Our results point to the need of a greater teaching effort on visual representations and their logical, symbolic and semiotic relationships with the rest of the mathematics involved. When observing the final results, the scores on task 2 (the simplest in our first opinion) were striking for us. It barely involved the calculation of basic areas and the relationship between the algebraic sign and the graphical position (height) of a point in the Real plane. Paradoxically, this was the task that yielded the worst performance in the three groups. Two explanations for this are: (a) Since it was a question that required basic high school skills, it was not addressed by us through any didactic situation. The low scores reflect that, even in the first semesters of university, Colombian students overlook these basic relationships. In response, we should design a series of didactic situations especially aimed at this issue. (b) Low scores in task 2 may also be due to the cognitive dissonance caused by the didactic contract (Brousseau, 2002). Students expecting tricky questions about functions and integrals, were surprised by a problem that asked for basic areas and algebraic signs (D'Amore, 2006).

Finally, we wanted to show a comparison of the final grades of the control and experimental groups. The current student's strike at the UNAL dramatically changed the 2024I academic calendar, preventing us from accomplishing this task. However, we hope to fill this gap soon.

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# Exploring eXtended-Based Learning Approaches in Portuguese Higher Education: A Study in Industrial Engineering and Management

Anabela C. Alves[1], Rui M. Lima[1], Diana Mesquita[2], M. T. Malheiro[3], Celina P. Leão[1]

[1] ALGORITMI/LASI 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 (CEDH), Portugal
[3] Center of Mathematics (CMAT-UM), Department of Mathematics, School of Sciences, University of Minho, Guimarães, Portugal

Email: anabela@dps.uminho.pt, rml@dps.uminho.pt, dmesquita@ucp.pt, mtm@math.uminho.pt, cpl@dps.uminho.pt

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**Abstract**

This paper presents a comprehensive study of what is named in this study as eXtended-Based Learning (xBL) approaches within the Portuguese educational landscape, including Problem-Based Learning (PBL), Project-Based Learning (PjBL), Challenge-Based Learning (ChBL), Service-Based Learning, and others. The study will contribute to characterizing different approaches being implemented by educators in Industrial Engineering and Management (IEM). Data was collected through the official website information about the curricular plans of IEM programmes, a survey by a questionnaire to universities (public and private) and polytechnic institutes that manage programmes in Industrial Engineering and Management and semi-structured interviews with six Industrial Engineering and Management educators. The interviews explored the educators' experiences, perceptions, and challenges in implementing these pedagogical approaches. With a particular focus on xBL approaches, the study explored the factors contributing to the successful implementation of xBL approaches, including institutional support, resource allocation, and institutional culture. This study intended to promote future investigations into the challenges and significance of educator training and the impact of training initiatives on teaching effectiveness and student learning outcomes. By highlighting each approach's unique characteristics and pedagogical benefits, this study provides educators and other stakeholders valuable insights for informed decision-making and effective implementation in different learning environments. Ultimately, the study contributes to the continuous improvement of pedagogical practices in Industrial Engineering and Management education in Portugal.

**Keywords:** Engineering Education; Industrial Engineering and Management; Active Learning; Project Based Learning; eXtended Based Learning.

## 1. Introduction

Students' generations evolve, and what seems to be enough for the previous (seating and hearing the teacher lecture in a classroom) does not seem enough for Generation Z, who are accustomed to the digital and technological world. At the same time, if they want to learn, they know at their fingertips and count on powerful generative artificial intelligence (AI) tools such as ChatGPT (Majeed & Hwang, 2024).

In light of these changes, Higher Education Institutions (HEIs) deal with many challenges and, in particular, Engineering Schools that must continue preparing the future engineering workforce for a volatile, uncertain, complex, and ambiguous (VUCA) world that conducts to a brittle, anxious, non-linear, and incomprehensible (BANI) world (Figueiredo, 2023). According to this author, students need skills like autonomy, leadership, curiosity, initiative, grit, resilience, creativity, teamwork, mindfulness, adaptability, empathy, critical and design thinking, and social sense to be prepared for this world. These are included in the needed competencies and skills reported by many organisations (Autodesk & ASME, 2022; Council of the European Union, 2018; Sala et al., 2020; World Economic Forum, 2015, 2018, 2022; World Manufacturing Forum, 2019). The key competences throughout life, according to the Council of the European Union (2018, p. 15), are: 1) Literacy; 2) Multilingual; 3) Mathematical, science, technology, and engineering; 4) Digital; 5) Personal, Social, and Learning to Learn; 6) Citizenship; 7) Entrepreneurship and; 8) Cultural awareness and expression.

Nevertheless, teachers need to use suitable pedagogical approaches for the students to develop such competencies. Figueiredo (2023) considered there are six new generation pedagogies: 1) explanation, 2) empowerment, 3) projective, 4) socialization, 5) drill, and 6) exploratory. According to this author, the first category, which includes traditional lectures, is overvalued, and the remaining five are undervalued or ignored. This categorization is also related to the one adopted by many authors that considered passive vs active learning methodologies, being "passive" mainly characterized by lectures (Bonwell & Eison, 1991; Felder & Brent, 2006; Felder & Silverman, 1988; Freeman et al., 2014; Lima, Andersson, et al., 2017; Prince, 2004).

In the context of active learning, it is possible to consider many approaches. For a description of several approaches, see, for example, Lima et al. (2024, p. 19). Active learning creates an environment for students to be creative, constructive, innovators and agents of their learning through an education that is continuously evolving from Education 1.0 to Education 5.0 (Alharbi, 2023; Chea & Huan, 2019; Costan et al., 2021; Dervojeda, 2021; Gerstein, 2013; González-Pérez & Ramírez-Montoya, 2022; Gowripeddi et al., 2021; Miranda et al., 2021). Many of these methodologies were referred to as X-based learning (Pecore, 2015, p. 160): case-based learning, community-based learning, game-based learning, passion-based learning, service-based learning, and team-based learning. Considering the specific case of project-based learning, this can take several forms or a combined form of designing and/or creating a tangible product, performance, or event, solving a real-world problem (may be simulated or fully authentic), and investigating a topic or issue to develop an answer to an open-ended question (Larmer, 2015).

This paper focuses on a subset of approaches referred to by Pecore (2015) that are more common in the context where the study was developed: Problem-Based Learning (PBL), Project-Based Learning (PjBL), Challenge-Based Learning (ChBL), Service-Based Learning, Case-Based Learning (CBL), Game-Based Learning, and Team-Based Learning. Inquiry-Based Learning (IBL) and Retrieval-Based Learning (RBL) were also considered since they can be included in different active learning methodologies in various ways, namely in the PBL and ChBL approaches (Friesen & Scott, 2013; Lechuga et al., 2024). Thus, this work aims to contribute to the characterization of different approaches implemented by educators in Industrial Engineering and Management (IEM) in Portugal by studying their practices.

This paper is organized into five sections. The first section introduces the context and objectives of the paper. Section two presents the study context. Section three presents the materials and methods used. The fourth section presents the results and discussion. The last section draws some conclusions.

## 2. Study context

The Portuguese Industrial Engineering and Management (IEM) programmes define the scope of the context of the study. This interest emerged as IEM educators at the University of Minho have applying Project-Based Learning since 2004 (Alves et al., 2020; Lima, Dinis-Carvalho, et al., 2017; Lima et al., 2007). The way they apply is different according to the curricular year and is constantly evolving, involving some or all courses, involving a company or not (Alves et al., 2019, 2012, 2017, 2023; Alves, Sousa, Fernandes, et al., 2016; Alves, Sousa, Moreira, et al., 2016; Alves & Leão, 2015; Lima, Dinis-Carvalho, et al., 2017; Sousa et al., 2023).

This experience empowered the authors to build a collaborative learning community around active learning approaches focused on solving open-ended problems. This community project was funded by Centro-IDEA-UMinho (https://idea.uminho.pt/pt/apoio-a-projetos/Paginas/default.aspx). Within its aims and actions, the Centre IDEA-Uminho supports Teaching & Learning Projects at the university that stimulate innovation and quality in teaching practices that benefit student learning. With this community, the authors expected to mobilize a group of teachers who have been developing Project-Based Learning (PBL) activities in engineering and extend it to all areas of the university and beyond who show interest in xBL approaches. Ideas are also expected to be shared, and these teaching/learning methodologies will be disseminated among the academic community. In this context, the authors are interested in understanding what other IEM colleagues are applying in the same field, as the competencies to be developed in each programme should be the same ( Lima et al., 2012; Lima et al., 2013; Mesquita et al., 2015). Based on a search on 30 March 2024, 18 Higher Education Institutions (HEIs) (universities and institutes) offer IEM programmes in Portugal. They are in Table 1. All of these programmes are first-cycle programme of three years (six semesters), corresponding to 180 European Credit Transfer System (ECTS). The second cycle corresponds to two years and 120 ECTS (four semesters).

Table 1. Portuguese institutions with IEM degrees

| Institution (name in Portuguese) | 1st cycle | 2nd cycle | Link |
|---|---|---|---|
| Instituto Politécnico do Cávado e do Ave | Yes | Yes | https://est.ipca.pt |
| Instituto Politécnico de Bragança | Yes | No | https://portal3.ipb.pt |
| Instituto Politécnico de Castelo Branco | Yes | No | https://www.ipcb.pt/estcb |
| Instituto Politécnico de Leiria | Yes | No | https://www.ipleiria.pt |
| Instituto Superior de Engenharia de Coimbra | Yes | Yes | https://www.ipc.pt |
| Instituto Superior de Engenharia de Lisboa | No | Yes | https://www.isel.pt |
| Instituto Superior de Engenharia do Porto | Yes | Yes | https://www.isep.ipp.pt |
| Instituto Superior Técnico de Lisboa | Yes | Yes | https://tecnico.ulisboa.pt |
| Universidade da Beira Interior | Yes | Yes | https://www.ubi.pt |
| Universidade de Aveiro | Yes | Yes | https://www.ua.pt |
| Universidade de Coimbra | Yes | Yes | https://apps.uc.pt |
| Universidade de Trás-os-Montes e Alto Douro | Yes | No | https://www.utad.pt |
| Universidade do Minho | Yes | Yes | http://www.dps.uminho.pt |
| Universidade do Porto | Yes | Yes | https://fe.up.pt |
| Universidade Lusíada (Famalicão) | Yes | Yes | https://www.fam.ulusiada.pt |
| Universidade Lusófona | Yes | Yes | https://www.ulusofona.pt |
| Universidade Nova de Lisboa | Yes | Yes | https://www.fct.unl.pt |
| Universidade Portucalense | Yes | No | https://www.upt.pt |

## 3. Materials and methods

This study employed a mixed-methods approach to investigate Higher Education Institutions' (HEIs) perceptions and practices regarding integrating active learning approaches in IEM education. Integrating quantitative and qualitative methods in this study offers a holistic understanding of the complex phenomenon of active approaches implementation in IEM education within HEIs (Morgan, 2014). Quantitative data provide breadth and generalizability, while qualitative insights offer depth and context. Together, these approaches provide a nuanced understanding of the multifaceted nature of technology integration, informing evidence-based recommendations for policy and practice within HEIs. The research methodology involved three main stages: 1) HEI website consultation through the links provided in All of these programmes are first-cycle programme of three years (six semesters), corresponding to 180 European Credit Transfer System (ECTS). The second cycle corresponds to two years and 120 ECTS (four semesters).

Table , searching for xBL approaches that could be referred to in the website, 2) application of an online questionnaire, and 3) semi-structured interviews. The procedure used for these last two stages is explained in the following sections.

### 3.1 Online Questionnaire

The quantitative component, conducted through an online questionnaire, aims to gather quantitative and qualitative data on various aspects of identifying which and how these active learning approaches focused on open problem-solving are used in the IEM community. Identifying the factors contributing to these approaches' successful implementation is also expected. Participants were asked to respond to closed- and open-ended questions, allowing for the systematic analysis of trends and patterns across institutions. The quantitative analysis will quantify the extent of implementation and integration of active approaches. The online questionnaire was divided into four sections after a short context presentation, as presented in Table 2.

Table 2. Questionnaire sections and questions identification

| Sections | Nr of questions | Questions type |
|---|---|---|
| 1. Identification (optional) | 3 | Short answer |
| 2. Courses identification | 8 | Mixed |
| 3. Courses detailed characterization | 17 | Mixed |
| 4. Other aspects (optional) | 1 | Open-ended |

Initially, emails with links to the online questionnaire and the study's primary objective were sent to all directors of the programs within the IEM field. Subsequently, employing a snowball sampling technique, these directors were asked to forward the email invitation to individuals within their networks who were knowledgeable about the area. Also, the research team members send to their counterparts, allowing for the recruitment of a diverse and representative group of participants with expertise in the subject matter. Furthermore, building upon this network, the questionnaire was sent to 87 IEM educators of different Portuguese HEIs and distributed according to Table 3. It was initially launched on 25 March 2024 and asked for answers until 03 April. Subsequently, the deadline was extended until 14 April to accommodate additional responses. This table also presents the number of respondents. The response rate was approximately 27%.

Table 3. Number of questionnaires sent to IEM educators of different HEIs and number of respondents

| Institution (name in Portuguese) | Nr | Resp. |
|---|---|---|
| Instituto Politécnico do Cávado e do Ave | 1 | |
| Instituto Politécnico de Bragança | 11 | |
| Instituto Politécnico de Castelo Branco | 1 | 1 |
| Instituto Politécnico de Leiria | 1 | |
| Instituto Superior de Engenharia de Coimbra | 6 | 1 |
| Instituto Superior de Engenharia de Lisboa | 4 | |
| Instituto Superior de Engenharia do Porto | 6 | 4 |
| Instituto Superior Técnico de Lisboa | 2 | 1 |
| Universidade da Beira Interior | 4 | |
| Universidade de Aveiro | 14 | 2 |
| Universidade de Coimbra | 6 | 1 |
| Universidade de Trás-os-Montes e Alto Douro | 3 | 1 |
| Universidade do Minho | 5 | 5 |
| Universidade do Porto | 3 | |
| Universidade Lusíada | 1 | 1 |
| Universidade Lusófona | 9 | 2 |
| Universidade Nova de Lisboa | 8 | 3 |
| Universidade Portucalense | 1 | 1 |
| Total | 86 | 23 |

## 3.2 Semi-Structured Interviews

Complementing the quantitative findings, the qualitative component of semi-structured interviews delves deeper into the underlying factors and contexts shaping the integration practices within HEIs. Through open-ended questions and probing discussions, qualitative inquiry captures the richness of participants' experiences, perceptions, and perspectives.

A group of six teachers and researchers in IEM were selected from the list of those who answered the online questionnaire. Two authors conducted the semi-structured interviews individually with participants online, each lasting approximately 45 minutes to 1 hour. Prior consent was obtained from all participants for audio recording to aid in subsequent study and analysis. Given the time needed to present the results, one of the criteria used for selection was availability in the study's time frame. However, the aim is to extend the interviews to a broad group that includes at least one lecturer from each HEI. As the interview progressed, key topics related to the implementation and impact of xBL were covered, including (1) exploring teaching methodologies, (2) identifying challenges, (3) understanding perceived outcomes, and (4) how the interviewee evaluated the success of the approach used. Also, the potential and the need for specific use of the software were identified. Probing questions were used to delve deeper into specific areas of interest, extracting detailed insights from the participants and encouraging them to provide examples and elaborate on their responses.

Table 4 shows the interviewees' main characteristics: gender, whether the primary training area is IEM (Yes/No), which area they teach, and their knowledge of xBL (Low, Medium, or High).

Guidelines were developed to guide the semi-structured interviews and ensure they yield comprehensive insights into the implementation and impact of active learning approaches in IEM. Firstly, the purpose of the interview was introduced, the context of the research objectives was provided, and the pivotal role of the interviewee's contributions to the study was underlined. The insights are not just valuable, but they are instrumental in shaping the understanding of active learning in IEM. Open-ended questions were designed to encourage participants to share their perspectives freely. These questions focused on the interviewees' experiences with active learning methodologies in IEM education.

As the interview progressed, key topics related to the implementation and impact of xBL were covered, including (1) exploring teaching methodologies, (2) identifying challenges, (3) understanding perceived outcomes, and (4) how the interviewee evaluated the success of the approach used. Also, the potential and the need for specific use of the software were identified. Probing questions were used to delve deeper into specific areas of interest, extracting detailed insights from the participants and encouraging them to provide examples and elaborate on their responses.

Table 4. The main characteristics of the IEM educators interviewed

| ID | Institution (in Portuguese) | Gender | IEM core curriculum? | IEM's main area of teaching | Level of knowledge of xBL approaches |
|---|---|---|---|---|---|
| 1 | Instituto Politécnico de Castelo Branco | Male | Yes | Simulation | Low |
| 2 | Instituto Superior de Engenharia do Porto | Male | No | Simulation | Medium |
| 3 | Instituto Superior de Engenharia do Porto | Male | Yes | Quality/Project Management | Low/Medium |
| 4 | Universidade Nova de Lisboa | Female | No | Entrepreneurship | High |
| 5 | Universidade Nova de Lisboa | Female | Yes | Business Management | High |
| 6 | Universidade Lusíada | Female | No | Economic Project Evaluation | Medium |

In closing, a summary of the key points discussed during the interview was presented to ensure clarity and understanding. Also, participants were invited to share any additional insights or thoughts and give advice to other educators interested in implementing active learning approaches in the field of IEM. Lastly, they expressed sincere gratitude for the time and valuable input. Each participant signed an informed consent agreement before each interview.

# 4. Results and discussion

This section discusses the results obtained from the different sources.

## 4.1 Website information

Institution websites were consulted to retrieve helpful information on xBL approaches. As depicted in Table 5, nearly every university offers a Curricular Unit (CU) titled "Project" or a similar name. The primary objective of this CU is to cultivate the capacity to synthesize knowledge from various disciplines, foster an integrated perspective, and nurture soft skills such as teamwork, interpersonal communication, time management, responsibility, and leadership. Interestingly, two universities (Universidade Lusófona and Universidade Portucalense) explicitly mention using Active Learning methodologies. However, only the University of Minho specifies adopting a Project-Based Learning approach. Based in this information, most IEM degrees indicate a project and/or an internship in the last semester of the programme.

Table 5. Curricular Unit (CU) Project in IEM degrees

| Institution | *CU* named *Project* | Observations |
|---|---|---|
| Instituto Politécnico de Bragança | In the last semester | |
| Instituto Politécnico de Castelo Branco | In the last semester | Could be an *Internship* |
| Instituto Politécnico de Leiria | In the 5th semester | *Industrial Project* |
| Instituto Politécnico do Cávado e do Ave | In all semesters | |
| Instituto Superior de Engenharia de Coimbra | In the last semester | Could be an *Internship* |
| Instituto Superior de Engenharia de Lisboa | No | |
| Instituto Superior de Engenharia do Porto | Every year, annual | *Interdisciplinary Project* |
| Instituto Superior Técnico de Lisboa | In the last semester | *1st Cycle Integrative Project in Industrial Engineering and Management* |
| Universidade da Beira Interior | No | |
| Universidade de Aveiro | In the last semester | *Project in Industrial Engineering and Management* |
| Universidade de Coimbra | No | |
| Universidade de Trás-os-Montes e Alto Douro | No | |
| Universidade do Minho | One semester per year | *Project in Industrial Engineering and Management* |
| Universidade do Porto | In the last semester | *Project in Industrial Engineering and Management* and *Project FEUP* in the 1st semester |
| Universidade Lusíada | In the last semester | Could be an *Internship* |
| Universidade Lusófona | In the last semester | |
| Universidade Nova de Lisboa | In the last semester | *Project in Industrial Engineering and Management* and *Transversal Skills for Science and Technology*, in the 2nd semester |
| Universidade Portucalense | No | *Internship* in the last semester and *Transversal Skills for Science and Technology*, in the 1st semester |

## 4.2 Questionnaire

The presented results illustrate the participants' opinions and practices, reflecting the 23 responses from the online questionnaire. Despite the relatively low response rate to the questionnaire (27%), it is a valuable indicator of teachers' perspectives and attitudes toward the topic under analysis. Regarding which xBL approach(es) is/are implemented in the course(s), the most commonly identified was Project-based learning

(33%), followed by Problem-based learning (21%), then Challenge-based learning with 19%, and then Team-based learning (8%) (Figure 1a). Retrieval-based learning and Game-based learning with 6% each, Inquiry-based learning with 4%, and Service-based learning with 2%.

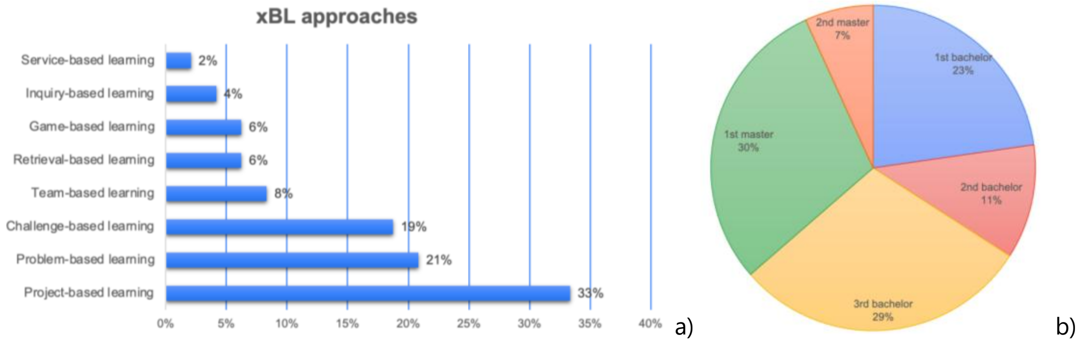


Figure 1. a) xBL approaches implemented according to the survey, b) Degree level of xBL approaches implemented

All the participants were course coordinators, however, 19% mentioned that the coordination of the course is dynamic and undergoes periodic changes, in some cases every two years. As illustrated in Figure 1b, xBL practices are more frequently implemented in the first year of the master's program (30%) and in the third year of the bachelor's degree (29%). The first year of a bachelor's degree appears in third place with 23%. Two participants reported that the project proposed to the students is in more than just the context of a curricular unit. It is also in the context of a real problem defined by a company.

Regarding competencies developed by students, the participants referred to an equilibrium between technical and transversal. Teamwork, time and conflict management, and critical thinking were identified as students' main transversal competences. The main deliverables assessed were oral presentations and reports (43%). Nevertheless, 22% of participants referred to an individual test as part of the evaluation methodology.

Regarding the presence of a tutor for a team of students, 4% mentioned that this role does not exist, and 17% did not answer this question. Based on the other answers, 70% mentioned that the tutor is simultaneously a teacher of the course, 22% said that the tutor is a teacher who is not from the course, and 13% said that also a student-tutor is a member included.

Since students' work is developed in a team, there is a question regarding how and if peer assessment influences individual student evaluation. Most participants (65%) referred to peer assessment as influencing the team's final grade through a correction factor. Nevertheless, 35% stated that it does not have an influence. One participant mentioned that it provides some clues for assessing group work, which is then done by the course instructors.

### 4.3 Interviews

The qualitative findings from the six semi-structured interviews will be presented, complementing the previous qualitative analysis (Table 4). These six interviews were not mere question-answer sessions but interactive discussions that delved into key topics related to the implementation and impact of active learning methodologies. Participants shared insights on teaching methodologies, identified challenges, and discussed their approaches' perceived outcomes.

All interviewees participants agreed on the evolving trends in education, particularly in response to the characteristics of new generations. They emphasized the importance of educators adapting their teaching approaches and recognizing contemporary students' unique needs and preferences. For example, "*working in*

*Agile SCRUM*", quoted by ID4. ID1 also referred to the need to introduce a project-integrated course as demanded by the national accreditation agency and smiling, he said "*this probably was influenced by the PjBL developed in University of Minho*". This collective viewpoint underscores teachers' need to remain cognizant of evolving educational paradigms and tailor their pedagogical strategies to effectively engage and support learners in today's dynamic educational landscape. However, it is noteworthy that two participants specifically highlighted the significance of knowledge transmission as the most critical issue that must not be overlooked:

ID3 and ID5: "*Knowledge transmission*".

This opinion reflects the traditional thinking that a teacher should transfer knowledge, contrasting the teacher's role as a facilitator of student learning (Zhang et al., 2008). Nevertheless, this role change demands effort and time, which is not recognized in teachers' professional career progression. Furthermore, it is noteworthy that two participants explicitly expressed a keen interest in deepening their understanding and mastery of active methodologies, particularly Project-Based Learning at the undergraduate level. Their enthusiasm reflects a growing recognition of the potential benefits and effectiveness of PjBL in fostering student engagement, critical thinking, and real-world application of knowledge. This eagerness to explore and embrace innovative pedagogical approaches underscores a proactive stance towards professional development and a commitment to enhancing teaching practices to better meet students' evolving needs. Additionally, interviewees evaluated the strategies' success and highlighted the potential and necessity for specific software applications.

# 5. Conclusions

This paper presents a preliminary study about several active learning approaches included in what was named eXtended-Based Learning Approaches explored in Portuguese Higher Education focused on Industrial Engineering and Management programmes. The results achieved are interesting, showing an interest of IEM educators in renewing their practices but, at the same time, unaware of what xBL approaches really are. Many educators need a clearer picture of those practices and do not put them in the same package. That is, there is a general misunderstanding about the identification of the xBL approach. The use of "problem", "project" and "challenge" for the same approach, or the identification of all three knowing that only one was applied. However, the respondents are actively looking to transform their classes into more active classes, using or not the approaches referred to in this paper. Nevertheless, the results are limited, as just a response rate of 27% was obtained through the questionnaire. The interviewed teachers are only a small sample of the 18 IEM programmes in Portugal. The preliminary findings resulted from an exploratory analysis of the collected data. Subsequent stages will entail an integrated analysis to comprehensively examine eXtended-Based Learning (xBL) approaches within the IEM curriculum in Portugal.

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# Integration of Mathematical Modelling in Engineering Education: A Qualitative Study on Differential Equations

John Jairo Leal Gómez[1], Juan Pablo Cardona Guio[2]

[1] Universidad Nacional de Colombia Sede Palmira. Facultad de Ingeniería y Administración. Departamento de Ciencias Básicas
[2] Universidad Cooperativa de Colombia, Sede Bogotá. Facultad de Ingeniería

Email: jlealgom@unal.edu.co, juan.cardonag@ucc.edu.co

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**Abstract**

This study conducts a qualitative assessment of mathematical modeling in engineering education via a differential equations course at the Universidad Nacional de Colombia, Palmira Campus. By focusing on individual environmental engineering student projects that apply the finite difference method, the research explores solving real-world environmental problems. It highlights the educational benefits, such as enhanced understanding of complex mathematical concepts and improved problem-solving capabilities. Specific instances, like water pollution and pollutant dispersion modeling, illustrate the practical relevance and effectiveness of these educational strategies. The findings suggest that integrating a robust mathematical modeling component within engineering curricula not only develops students' analytical skills and engagement but also equips them to tackle modern challenges with advanced tools, fostering a comprehensive and applied educational approach.

**Keywords**: Mathematical Modeling, Engineering Education, Differential Equations, Applied mathematics

## 1 Introduction

At the National University of Colombia, Palmira Campus, in a differential equations course, the proposed methodology was used that includes mathematical modeling techniques, emphasizing the practical application and analysis of concepts through individual environmental engineering projects. Such projects involved solving both ordinary and partial differential equations and allowed each student to become deeply involved in relevant engineering problems of her interest. The idea was to use mathematical modeling techniques to expand knowledge of the selected systems.

The students consulted specialized databases, and master's or doctoral theses until they found their target system, for which they defined the variables, and selected and applied the mathematical model that they considered most appropriate according to the reference document and the guidance of the professors. Once the model and the initial or boundary conditions were selected, the students used analytical or numerical techniques -depending on the case- to solve the system. In the case of numerical techniques, they used Python to do the simulation. Finally, they validated the model with specialized literature.

Through this method, students not only strengthened their understanding of differential equations but also developed essential skills to model, analyze, and solve more complex challenges. This educational strategy effectively prepares them for real-world engineering tasks by fostering both theoretical knowledge and practical problem-solving skills.

## 2 Introduction to Mathematical Modeling in Engineering Education

The task of engineers is to model and mathematically study complex systems, which is why it has been incorporated into engineering study plans (Cardona & Leal, 2020; Cardona & Leal, 2024; Leal & Cardona, 2015; Froyd, Wankat, & Smith, 2012; Strobel, & Pan, 2011; Velten, 2009 ). Engineers who model a complex system must select the variables, and select or use models through ordinary, partial differential equations or other techniques, which will then be solved using analytical or numerical tools and simulations (Magana, 2017), to validate such solutions that account for the behavior of the system, see the cycle in figure 1. This approach fosters a deeper understanding of mathematical concepts and promotes essential skills for solving real problems in fields ranging from environmental engineering to system dynamics (Cellier, 1991; Palusinski & Wait, 1978).

The proposal is to incorporate mathematical modeling tools in mathematics courses for engineers, an educational strategy that seeks to improve skills in the study of complex systems and practical applications (Hamilton, Lesh, Lester, & Brilleslyper, 2008; Alpers, 2017; Litzinger, Lattuca, Hadgraft and Newstetter, 2011). As the engineering landscape evolves, strengthening mathematical and computational training becomes crucial to meet industry demands and foster the development of competent, innovative, and efficient professionals (Fortenberry, Smith, McKenna, Knapp, & Cady, 2007; Litzinger, Lattuca, Hadgraft, & Newstetter, 2011).

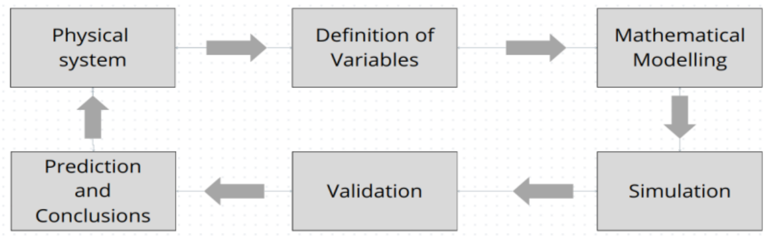


Figure 1. Mathematical modeling cycle in engineering

To address educational challenges in engineering, various innovative teaching strategies have been proposed and implemented in some institutions, each enhancing understanding and retention through practical application:

- Problem-Based Learning (PBL): This method involves students in solving real-world engineering problems that require mathematical solutions, significantly enhancing understanding and retention. Howard S. Barrows (1996) has discussed the effectiveness of PBL, particularly in medical education, which is readily adaptable to engineering education to enhance problem-solving skills.

- Integrated Courses: Some programs have begun to integrate mathematics directly into engineering courses, teaching mathematical principles alongside their application in engineering tasks. Owens and Fortenberry (2007) highlight the importance of integrating educational research into course design, thus enhancing the practical application of theoretical concepts.

- Technology-Enhanced Learning: Utilizing software and simulations can make the abstract nature of mathematics more tangible by visualizing complex engineering problems and their solutions. Prince and Felder (2006) advocate for inductive teaching methods, including technology-enhanced learning, to improve the educational outcomes in engineering.

- Flipped Classrooms: This model, where students learn new content online by watching video lectures and then apply what they have learned in the classroom, fosters a more active learning environment and better engagement. Bishop and Verleger's (2013) research on flipped classrooms provides evidence of its effectiveness in engineering education, promoting active and engaged learning.

Our proposal includes different aspects of the innovative techniques presented, incorporating mathematical modeling techniques, computational tools, and analysis of complex systems, which will be solved using numerical methods.

# 3 Practical Applications in Environmental Engineering

At the beginning of the differential equations course for engineers, the methodology was proposed; each student had to select an application problem of their interest, which was related to ordinary or partial differential equations in their field. We are going to present two cases that were studied, namely, a pollution model of a lake (static case) and a pollutant dispersion model in a river (dynamic case).

## 3.1 A Modeling Using Partial Differential Equation in Environmental Engineering:

In the next part, we present some important applications that could be studied using partial differential equations.

**Applications of Laplace's equation in environmental engineering**

The Laplace equation with boundary conditions is a special form of the Poisson equation, which has no source terms and is used in contexts where the field being modeled is harmonic. It can be used to model different physical systems, in this case, it was used to model water pollution in a lake where there is a stationary distribution of pollutants under equilibrium conditions, that is, when there are no additional sources or sinks of pollution. This means that in the studied region, the concentration of pollutants does not change abruptly in space under stable conditions, and it is assumed that there is no production or destruction of pollutants. Although these are ideal conditions, in the context of environmental engineering, it is very useful for understanding the system being studied and pose a critical problem for engineers.

**Some applications of this model could be:**

- **Groundwater Flow Modeling:** The Laplace equation could be applied to model the flow of contaminated groundwater when the flow is steady and there are no inputs or outputs of contaminants.
- **Pollutant Distribution:** In bodies of water such as lakes or ponds where conditions are relatively stable and water movement is minimal, the Laplace equation could help determine the spatial distribution of the pollutant under assumptions of a steady state.

**Applications of the Advection-Diffusion equation in environmental engineering**

The reaction-advection equation is a mathematical formulation in partial derivatives used in various fields to model the transport and chemical transformation of substances within a moving medium. This equation combines terms that represent the physical movement (advection) of a substance due to the flow of the medium, along with terms that describe chemical or biological changes (reaction) that affect the substance during its transport. For the second project, the pollution of a river was chosen, a problem in which this equation is crucial to simulate how a pollutant disperses along the river and reacts with other chemical components of the water, an essential model to predict the evolution of contamination and thus be able to plan effective mitigation and cleanup strategies.

**Some applications of this model could be:**

- **Pollutant Dispersion in Rivers and Streams:** The equation is used to predict how pollutants disperse in a river or stream following an accidental spill. By understanding how the pollutant concentration changes over time and space, effective mitigation strategies can be developed to minimize environmental damage.
- **Atmospheric Pollution:** The Advection-Diffusion equation models the spread of pollutants in the atmosphere. It can predict the distribution of smoke from wildfires, the dispersion of pollutants from industrial chimneys, or the spread of odors in urban areas.

- **Groundwater Contamination:** In hydrogeology, the equation helps simulate how contaminants move through the subsurface water system. This is crucial for assessing the risks to drinking water sources from contaminants like pesticides, industrial chemicals, or leachate from waste disposal sites.
- **Chemical Spills in Oceans and Lakes:** For marine and lacustrine environments, the equation models how substances such as oil or chemical spills spread in the water body, influencing cleanup strategies and ecological risk assessments.
- **Heat Transfer in Fluids:** Although not a pollutant, the equation also applies to thermal diffusion in fluids, helping engineers and environmental scientists understand and predict the temperature distribution in natural and engineered water bodies, which is vital for ecological health assessments.

**Description of finite differences method:**

In both cases, the finite difference method was used to simulate the behavior of the equations, which consists of discretizing the derivatives using approximations, resulting in an algebraic system of equations that was solved and graphed using the Python program (Faires & Burden, 2012; Velten, 2009; Allaire, 2007).

Once we have the model and the initial and boundary conditions, we proceed to solve the equation. In our case, using the finite difference method, the problem domain is first initially discretized by dividing space and time (if relevant) into a grid of points. Each point in this grid represents a node at which the values of the solution function will be approximated. Instead of solving the differential equation directly, the derivatives are replaced with finite differences, which are algebraic expressions that are approximately equivalent to the derivatives.

For example, in the case of a second-order partial differential equation, the partial derivatives concerning space can be approximated using centered differences, $\frac{\partial^2 u}{\partial x^2} \approx \frac{u(x+h,y)-2u(x,y)+u(x-h,y)}{h^2}$, for the second derivative in the x-direction, where h is the distance between adjacent nodes on the x-axis of the grid. Similarly, it applies to other spatial dimensions or the time derivative if the equation is time-dependent.

Below we present some applications of problems taken from reality, developed by students in the projects making the corresponding simplifications.

## 3.2 Pollution Model in a Square Lake:

To address the pollution model, an approach was made using a square lake where one of the borders has a source of pollution and the others have zero concentrations of pollutants. We proceed as follows:

**Scenario**

- **Lake Dimensions:** Suppose the lake has dimensions of $a \times a$ to simplify the analysis, with $a$ being the length of each side of the square lake.
- Location of the Pollution Source: The source of contamination is located on one of the sides of the square, for example, on the side where $x = a$.

**Mathematical model**

We use Laplace's equation to describe the stationary distribution of the contaminant in the lake:

$$\nabla^2 c = 0$$

where $c(x, y)$ is the concentration of the pollutant.

Or more explicitly in Cartesian coordinates, it is written as:

$$\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2} = 0$$

where $c$ is the potential function being solved for, and $\frac{\partial^2}{\partial x^2}$ and $\frac{\partial^2}{\partial y^2}$ are the second partial derivatives with respect to the x and y coordinates, respectively.

**Boundary conditions**

- At $x = a$ (where is the source of contamination): $c(a, y) = f(y)$, where $f(y)$ could be a function that describes how the pollutant concentration varies along this boundary, e.g. $f(y) = C$ being $C$ constant, use $f(y) = C(1 - (y/a)^2)$ to give greater concentration in the center and less towards the ends.
- On the other three edges of the square: $c(0, y) = 0$, $c(x, 0) = 0$, y $c(x, a) = 0$.

**Solution**

Given the symmetry of the problem and the boundary conditions, the solution can be approximated using numerical or analytical methods such as the separation of variables. However, a common approach to solving these types of problems in a rectangular or square domain with mixed boundary conditions is to use the finite difference method.

**Discretization and finite differences**

- **Domain discretization:** Divide the lake into a square mesh of points with increments $\Delta x = \Delta y$.
- **Apply the finite difference approximation:**

$$\frac{c_{i+1,j} - 2c_{i,j} + c_{i-1,j}}{\Delta x^2} + \frac{c_{i,j+1} - 2c_{i,j} + c_{i,j-1}}{\Delta y^2} = 0$$

  for each interior point of the mesh.

- **Solve the system of linear equations in python:** resulting for the values $c_{i,j}$ at the nodes of the mesh.

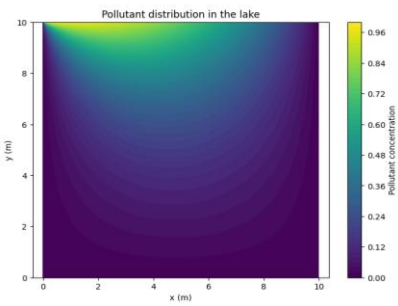


Figure 2. Solution for lake pollution using Laplace's equation

In Figure 2 you can see the solution of Laplace's equation, obtained using the finite difference method in Python. In which you can see how the contaminant is distributed in the lake. It can be seen that at the upper border where it was "applied", the pollutant has a greater concentration and it diffuses as we move away from that border.

## 3.3 Modeling Contaminant Dispersion in a River Using the Advection-Diffusion Equation

Modeling the dispersion of a contaminant in a river using the advection-diffusion equation with appropriate initial and boundary conditions.

**Model Setup**

**Scenario** Consider a river where a contaminant has been accidentally released at a specific point. We aim to model how this contaminant disperses downstream over time due to the river's flow and natural diffusion processes.

**Mathematical Model** We use the advection-diffusion equation to describe the contaminant's concentration in the river:

$$\frac{\partial c}{\partial t} + v\frac{\partial c}{\partial x} = D\frac{\partial^2 c}{\partial x^2}$$

where:

- $c(x,t)$ represents the concentration of the contaminant at position $x$ and time $t.v$ is the velocity of the river's flow (assumed constant for simplicity).
- $D$ is the diffusion coefficient of the contaminant in water.
- $\frac{\partial c}{\partial t}$ is the partial derivative of concentration with respect to time, indicating how the concentration changes over time at a fixed position.
- $v\frac{\partial c}{\partial x}$ represents the advection term, showing the change in concentration due to the movement of the fluid.
- $D\frac{\partial^2 c}{\partial x^2}$ is the diffusion term, describing how the concentration changes due to the spreading and mixing of the contaminant.

**Initial and Boundary Conditions**

To solve the advection-diffusion equation, we need to specify initial and boundary conditions:

- **Initial Condition:**

  $$c(x,0) = M\delta(x - x_0)$$

  This condition states that at time $t = 0$, the contaminant is introduced at position $x_0$ in a concentrated form, modeled as a Dirac delta function, where $M$ is the mass of the contaminant.

- **Boundary Conditions:**

  As $x \to \infty$, the concentration of the contaminant should vanish: $\lim_{x\to\infty} c(x,t) = 0$

  Similarly, as $x \to -\infty$, though less physically relevant for a river scenario, we also assume: $\lim_{x\to-\infty} c(x,t) = 0$

This model allows predicting the concentration of the contaminant at different points in the river and at different times, which is crucial for planning mitigation and cleanup measures, Figure 3. For example, we can predict which areas will be most affected and when the contaminant is expected to arrive, allowing for a more effective response to protect public health and the environment. It is also useful for designing effective monitoring systems and for evaluating the environmental impact of future industrial activities in areas near bodies of water.

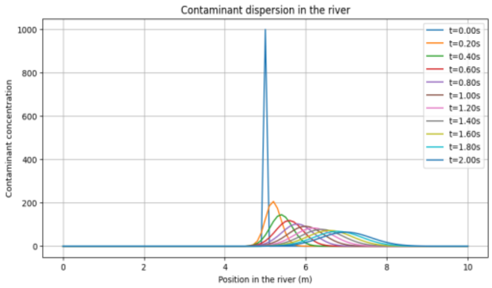


Figure 3. Contaminant dispersion in the river

# 4 Evaluation of the Impact and Future of Mathematical Modeling in Engineering Education

Below are the main analyses of the research presented.

## 4.1 Learning Outcomes

The implementation of practical projects within the differential equations course has significantly enhanced students' conceptual understanding. By applying mathematical models, students have gained a deeper grasp of complex phenomena such as advection and diffusion, using these principles to solve real-world problems like pollutant dispersion in rivers. Qualitative evidence from the course includes testimonials from students who report increased confidence in tackling complex mathematical problems and observations from instructors who note greater clarity in students' explanations and solutions. Previous studies support these findings, indicating that 70% of students find it easier to understand mathematical concepts when they can apply this knowledge to practical, real-world problems. Additionally, a survey conducted in the course revealed that 75% of students felt their problem-solving skills improved due to these projects.

## 4.2 Student Participation

Student motivation and engagement increased significantly since the introduction of this methodology. According to a recent survey conducted on the course, 85% of students reported feeling more motivated and attracted to the course. This increase in active participation has led to more dynamic class discussions and greater collaboration on group projects. Students expressed that adapting the projects to real-life problems has helped them see the practical value of differential equations, thus increasing interest and engagement in learning. One student commented, “Now I understand what differential equations and mathematics are for in my career,” reflecting on the common sentiment. Additionally, class attendance rates have improved by 15% since this approach was adopted.

## 4.3 Feedback from Students and Teachers

The comments from both students and teachers have been very positive. Students highlighted the effectiveness of the projects in helping them understand concepts and develop practical skills. One student noted, “The hands-on projects made the abstract concepts a lot clearer.” They have also expressed the difficulties that this type of projects have, from searching for the topic to solving the simplified problem.

Teachers have also rated the methodology favorably, observing that students show a greater ability to apply what they have learned in real-world contexts. However, teachers suggest that greater technical support from specialists in the topics is necessary, and the need to obtain additional resources that facilitate the implementation of more complex projects. They recommend incorporating more advanced software tools to improve student learning experiences.

### 4.4 Evidence for Learning Differential Equations

Academic results have improved since the adoption of this methodology. On exams, students showed a 20% increase in average grades compared to previous cohorts. Furthermore, the projects presented demonstrate a deep knowledge and correct application of differential equations. Specific case studies, such as the pollutant dispersion model in a river, were particularly successful, showing detailed graphs and precise analyzes that support learning and practical application of the concepts studied. These results indicate that incorporating mathematical modeling tools is not only effective in improving theoretical understanding, but also essential in developing crucial practical skills for engineers. An analysis of pre- and post-course assessments showed a statistically significant improvement in students' understanding of differential equations.

### 4.5 Comparison with Other Educational Approaches

Compared to other teaching methods, such as problem-based learning (PBL) and flipped classrooms, the mathematical modeling approach has clear advantages. Students not only learn theoretical concepts but also develop analytical and numerical problem-solving skills applied to practical situations. However, this approach also presents challenges, such as the need for additional resources and specialized training for teachers, who must collaborate with their engineering peers. Despite these limitations, the benefits outweigh the difficulties, offering a more comprehensive and applied educational experience.

### 4.6 Future of Mathematical Modeling in Engineering Education

Looking ahead, the integration of emerging technologies such as artificial intelligence and machine learning can further enrich the teaching of differential equations. Proposals to incorporate these technologies include using advanced software for more accurate simulations and personalizing learning to meet individual student needs. Furthermore, it is crucial that education policy makers support these initiatives through investments in educational technology and ongoing teacher training. Adapting curricula to technological advances and industry demands will ensure that engineering education remains relevant and effective, preparing students to meet future challenges. Future initiatives should also explore partnerships with industry to provide students with real-world project experiences, further bridging the gap between academic learning and professional application.

## 5 Conclusion

In conclusion, this study highlights the crucial role of using mathematical modeling tools to improve engineering education by effectively linking theoretical knowledge with practical application. This approach not only prepares students for the challenges of contemporary engineering, but also significantly increases their analytical and numerical problem-solving skills. Future research should delve deeper into the integration of mathematical models into various engineering courses and evaluate their long-term impact on career outcomes. As technology continues to evolve, educational strategies must adapt by incorporating emerging tools and interdisciplinary methods. This will ensure that students are equipped with the necessary skills to address future challenges and drive innovations in different fields of knowledge.

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# Peer Learning in Diverse Undergraduate Population in Networking and Distributed Computing Research

Pradeeban Kathiravelu[1], David Moxley[2]

[1] Department of Computer Science and Engineering, University of Alaska Anchorage, Anchorage, USA
[2] Department of Human Services, University of Alaska Anchorage, Anchorage, USA

Email: pkathiravelu@alaska.edu, dpmoxley@alaska.edu

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**Abstract**

Research has shown peer learning to provide a more welcoming environment to diverse student populations. Computer Science courses, such as Computer Networks, Distributed Computing, and Computer and Network Security, require multiple computers to test the developments beyond simulations, emulations, or virtual execution environments such as virtual machines. While each student is usually equipped with a personal computer, they must rely on computer labs to access research clusters for physically distributed executions. Such reliance poses additional hurdles. For example, students lack permission to install and run software on lab computers, and university security policies prevent students from running specific tasks, such as mimicking a network attack between two computer nodes in the university network for educational purposes. Students may use web-based computational resources such as Cloud Computing as an alternative. However, that incurs ongoing costs, often limited by the instructor's funding availability. This paper presents our approach to peer learning as student-driven group research projects in undergraduate classes. The instructor teaches these subjects as hybrid courses, with students joining in person or virtually. The classes consist of diverse student populations. This paper looks into our approach to incrementally defining student-driven networking and distributed computing research and their contribution to peer learning. In one instance, students conducted networking and distributed computing research on their personal computers, configured to communicate in a private network. They found such executions easier and more effective than installing and configuring several custom software in the lab computers, as those would require escalation for permission requests. We further present our incremental optimization process for these undergraduate research projects for an effective active learning environment.

**Keywords:** Active Learning; Engineering Education; Peer Learning; Project-Based Learning (PBL).

## 1 Introduction

Computer Science (CS) modules such as Distributed Computing and Computer Networks typically require the presence of a compute cluster for the projects to be implemented in a physical infrastructure. While many universities are equipped with such infrastructure, they limit the students' access to them as not all universities and schools have sufficient resources, especially when a group of students need access to those simultaneously. Some reserved labs also require physical presence to use their resources, which will challenge remote learners by requiring them to commute to their campus. Security is another concern that drives universities to limit students from configuring network applications that can communicate between computers. As an alternative strategy, researchers and learners use simulations(Breslau et al., 2000), emulations (Jurgelionis et al., 2011), and virtualized execution environments (Ammons et al., 2007) such as virtual machines (VMs). While they provide an alternative learning environment, they do not sufficiently provide the same realistic experience and exposure to the students as using a physical cluster developed with actual computers in a distributed manner.

Another commonly used approach is relying on cloud computing. However, that comes with additional limitations. First, while specific research labs are awarded with cloud credits from major cloud providers such as Amazon Web Services (AWS)(Cloud, 2011), Microsoft Azure(Wilder, 2012), and Google Cloud Platform (GCP) (Bisong & Bisong, 2019), they are not widely available to many non-R1/R2 universities in the US or many smaller universities globally. Furthermore, undergraduate courses such as Computer Networks cannot readily be taught in cloud environments as teaching cloud access and security are often outside the scope of these courses, given the limited time in the semester. Therefore, peer learning that utilizes students' devices works better in courses that require resources not readily available in undergraduate-focused universities. The goal of peer learning in collaborative courses such as Distributed Computing and Computer Networks and their associated research is to facilitate a student-driven research agenda without getting limited by the lack of resources in the research clusters by augmenting the computational resources in the labs with student's personal computers, by providing a seamless execution environment for students, between the research clusters in the labs and clusters that could be formed with the personal computers of student groups.

However, peer learning comes with further challenges in diverse environments. University of Alaska Anchorage (UAA) has a Carnegie Classification of "Master's Colleges & Universities: Larger Programs" (Shulman, 2001) and is an Asian American and Native American Pacific Islander Serving Institution (Nguyen et al., 2018). Anchorage is often cited as the most diverse city in the US. The top-3 most diverse schools in the US are all in the Anchorage School District (Farrell, 2018). With a (year 2023) population of 10,845 students with 5.43% American Indian/Native American, 7.26% Asian, 2.77% Black, 8.41% Hispanic/Latino, and 2.61% Native Hawaiian/Pacific Islander, UAA is often considered a minority-serving institution. In addition to its main campus in Anchorage, UAA has community colleges that serve Alaskan Native communities, who often transfer to complete their degrees at the Anchorage campus. A large fraction of UAA undergraduates are non-traditional students: Some are the first in their families to attend university. Some started university after the age of 25. Some have family responsibilities. Some are also full-time employees and/or the primary caretaker of a dependent in their house. For many such students, employment is necessary to finance their education. Many students do not follow the same academic path. Subsequently, a senior student often still can have several unfamiliar classmates. Consequently, UAA is blessed with a diverse student population.

This paper proposes peer learning in the context of undergraduate research group projects in networking and distributed computing modules. These hands-on projects leverage the undergraduates' computational resources to compose clusters for their research. The approach is tasked with understanding the human challenges associated with undergraduate group research projects in a diverse student population, especially with increased freedom to create and use their own research clusters through a well-defined framework provided by the instructor. Students are given the resources to develop their research clusters on their personal devices and work synergistically for individual and group success. Thus, we aim to promote active learning and peer learning among the students with minimal friction. Our early observations show that commuter students welcome this approach, as they could form groups with students who live nearby rather than commuting to the campus for their project implementation and group meetings. This freedom is crucial for a university that serves a large state such as Alaska, where classes are hybrid (students can join the class in person or remotely through Zoom). Catering to the two categories of students (those who primarily join in-person vs. those who mostly join remotely) and ensuring the teams consist of the same category of students (and incorporating location-based preferences and other parameters in group formations) are exciting research problems.

## 2 Motivation

Volunteer computing (Cunsolo et al., 2009) has allowed personal computational resources to be shared to execute larger complex computational tasks in a decentralized manner (Atre et al., 2021). However, volunteer computing typically focuses on sharing computational or network resources for a popular processing or network measurement task. Peer-to-peer (Milojicic et al., 2002) computation frameworks have helped create overlay networks and run distinct applications on top of them. However, peer-to-peer applications that can run on overlay networks are bound by the underlying physical network and its middlebox functions, such as firewalls. The overlay networks also cannot run many distributed systems as decentralized applications are a class of their own. Not all network applications can execute in such a peer-to-peer environment. This proposed project's technological complexity is relatively trivial. It merely connects the students' personal computers through switches and ethernet cables while ensuring security best practices are followed. The major contribution from this project comes from the academic challenges and interpersonal skills associated with carrying out such projects successfully. Facilitating a peer learning environment with established groups comes with challenges, including setting up student expectations, providing them access to the technical framework and network equipment (switches) as needed, and empowering them to quickly configure a secure private network for their projects. Since this will be a repeating task across modules, ensuring that the identified solution can be reproducible and optimizing it with each iteration are essential. Our approach, a paradigm shift in team formation and project definition, increases the computational capacity of the undergraduate student population by enabling them to leverage their personal computers to form research clusters quickly, using state-of-the-art networking developments.

In parallel to the students' research works on the topics, we also learn how student teams can function effectively towards undergraduate research, utilizing their shared computational resources and making their private networks across their devices. Our framework follows student-centric approaches to innovating pedagogy for project-based learning (Kokotsaki et al., 2016) in courses that benefit the most from such collaborative activities. While group projects are common in computer science and other STEM education, their efficiency in achieving learning outcomes with better student satisfaction in diverse education settings remains an important research topic. As a diverse university, UAA makes an excellent site for our associated research on student satisfaction and success in such project-based learning approaches. These group projects are formulated with students' direct inputs and directions with a larger degree of freedom for the student groups, including their implementation (in the form of software programming, deployment, and evaluation/benchmarking), demonstration (presentation, posters, or software executions), dissemination (code documentation, research papers, and conference talks), and archival (open-source in a GitHub repository). The project ideas are defined broadly for the students' interpretation and expansion rather than molding them into an inflexible project. However, to ensure direction and progress, continuous consultation for feedback is made compulsory with a well-defined framework with which students work. Such meetings are facilitated synchronously (face-to-face or virtually) and asynchronously via Email and Discord text communications.

While our project-based learning is carried out for the undergraduates enrolled in one department for the identified courses, some findings may be extended to other STEM educational settings, such as community colleges and high schools. Data collection regarding student satisfaction and demographics will involve human subjects. Therefore, we are preparing for the necessary Institutional Resource Board (IRB) approvals for more comprehensive surveys/questionnaires and a quantitative framework to measure student motivation, satisfaction, and success, supported by clearly stated consent forms. This quantitative framework will be developed parallel to the technical framework facilitating peer learning research groups. As such, our research combines innovations in networks and distributed systems and STEM education.

We identify Computer Networks, Distributed Computing, and related courses as the target for this project as these directly apply to the requirement of having multiple computers operating in a networked cluster. However, the lessons from this project can be generalized into other educational settings in similar 4-year public universities. By combining the pedagogical innovations in peer learning, project-based learning, group projects, and flipped learning (Yarbro et al., 2014) into the undergraduate computer science curriculum, specifically innovations in network and distributed computing architectures. We build a standard network framework that students can replicate using their personal laptops and utility network hardware to work on their group projects as a team in their own research clusters. While there is no scientific novelty in such network configurations, formalizing them into pedagogy to actively promote teams to be more interdependent on team members is an exciting innovation in computer science education.

## 3 Methods

As the first step, we prototyped a reusable network framework for the students to replicate. We discuss the security considerations and best practices needed for students to securely connect their computers to form clusters from the computer lab or homes when network switches and cables are available. We standardize this step so that we can repeat this across courses without additional repeated effort. Students work in teams from their preferred locations. This will benefit many students as UAA is a commuter campus, and many students tend to work outside the campus and often remotely on their group projects. Physical proximity to each other can be a defining factor in the success of the groups, which is considered when the groups are formed. Open-source execution frameworks are proposed with the networking hardware for communication across the student computers.

Figure 1 shows the private network formations of the teams, each team with four members by default (and five members when needed) connecting their devices via a network switch. Excess unused network hardware in the labs, such as NETGEAR 5-Port Gigabit Ethernet Unmanaged Switches (GS305) and RJ45 cables, allow students to connect their computers into clusters without configuring additional software. These switches cost less than 20 USD and are low-cost hardware compared to computers and enterprise software. Therefore, they can be easy to obtain and scale the teams. On top of that networked environment, students then deploy and execute their programs as well as open-source distributed execution environments such as Infinispan (Marchioni, 2012), Hazelcast (Johns, 2015), and GridGain (Samovsky & Kacur, 2012) In-Memory Data Grids (IMDG) (Guroob & Manjaiah, 2017) environments to allow running their software in a distributed manner.

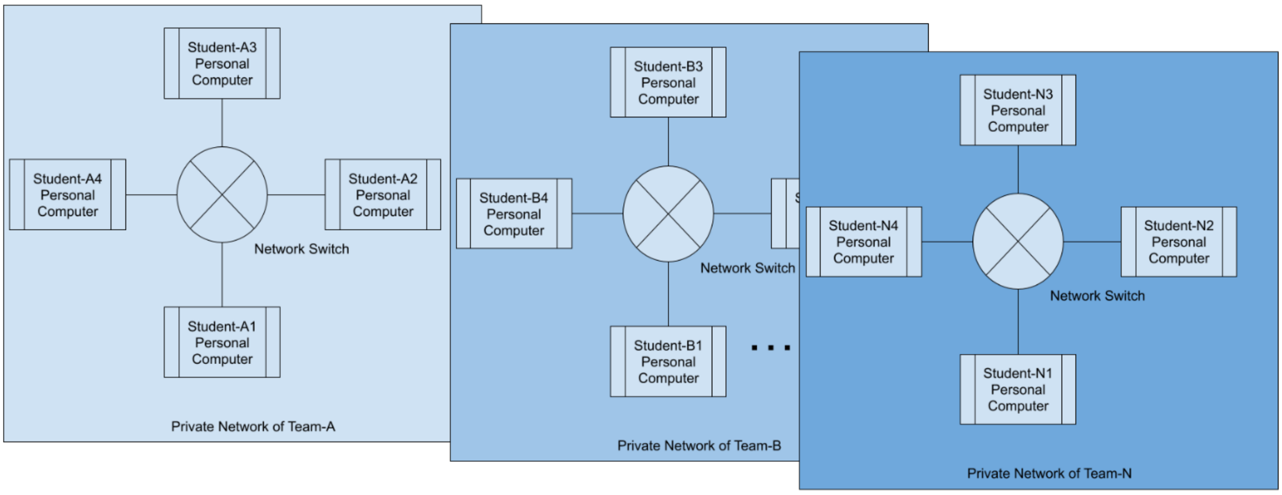


Figure 1. Private network clusters of the teams

The project and group formation consider the potential for one or at most two students from a team to drop out during the period of the course and group project. Such a dropout or withdrawal of students is indeed a potential across many classes. However, by carefully designing the problem, the impact of such a scaling down could be prevented. Computer and network security is critical, especially regarding data privacy, even in a private network. The students are trained in security and ethics to protect themselves and their teammates in such network deployments.

The instructor posts a list of potential project ideas (a title and a brief description/abstract) for each course early in the semester. Then, each student provides an ordered subset of their preferred topics from the list. Then, the instructor forms teams of students who show interest in working on the same topic, assigning the project ideas to the students who choose those with the highest preference as much as possible. There will be a wide range of project ideas for any student to choose from.

Once the teams are formed and the project ideas are assigned, the students follow a well-defined timeline, independently as teams, on their assigned topics. For the success of the projects, teams are formed considering their research interest (as indicated by their preferences on project ideas) and availability (students may be assigned to their second or third preference project if their higher preference projects have a higher demand). Demographics are considered in team formation so that students belonging to minorities in coding are not left alone in a team without a peer from a minority community. This ensures better participation from all the students. Teams are made diversely while considering such practical aspects. The teams are formed under the broadly defined project idea, in which the teams work together, with the instructor's input, to develop a more detailed problem statement and implementation from the instructor-provided project abstract. This team formation will be incrementally enhanced over the years as the instructor teaches the courses annually, considering student feedback and the overall quality of their research outcomes.

These projects are designed to enhance the students' higher-order skills defined in Bloom's Taxonomy. The learning outcomes are specified to improve students' creativity beyond what is achieved in a lecture-centric class or a classic group project where students work on a well-defined task provided by the instructor. The rubrics define the learning outcomes to ensure a thorough understanding of the problem. Sample learning outcomes from one of the group research projects from the class (on Computer and Network Security) are as in Listing 1.

*This activity corresponds to the below student learning outcomes:*

1. *Analyze potential risks in designing and implementing operating systems, databases, software, cloud, and networks.*
2. *Create innovative solution architectures adhering to the best practices of confidentiality, integrity, and availability, leveraging recent advancements in network security.*
3. *Evaluate threats and vulnerabilities in an organization, including physical and infrastructure security, human resources security, software security, network security, and data privacy.*

Listing 1. Learning outcomes from a group project.

These outcomes specifically target Create, Evaluate, and Analyze as their learning goals, instead of the projects where the students are tasked with Apply, Understand, and Remember skills. In addition, personal and professional capabilities (or transversal competencies), such as "organize group work and task distribution" and "document the evolution of the project work," are included as secondary learning outcomes. Each team will have a leader elected by the team and options to fire an idling teammate or quit when every other teammate does not contribute. The students who quit and those who are fired have to meet with the instructor to find alternative avenues to complete the assignment and receive a grade for the project. Students also have the option to switch teams in the early phases of the project with a valid reason. However, switching teams is discouraged since such changes contradict the instructor's original reasoning when forming the teams.

The project ideas posted for the students to choose from have sufficient details to ignite interest from the students (as by that time, they have a basic understanding of the topic but have yet to progress much into the course). Students are encouraged to meet with the instructor to clarify the topics before choosing one. Students work on expanding the idea into a fully-fledged project requirement to implement the solution for the task, following a flipped learning approach since most of the knowledge relevant to the topics is taught later in the course, whereas students start on the project early in the semester. Since these tasks are distinct across the projects, the student presentations by the end of the semester will be educational, and the instructor and other students will be able to learn from the students who present their work. Two sample project ideas (among the 14 listed for the Fall 2023 semester of the Computer Networks course) are shown in Listing 2.

The rubrics also include points to be given by the teammates and students from other teams as they evaluate the projects' outcomes based on a demo. In a sample group project of 10 points, the instructor awards 6 points, whereas students award the other 4 points. Each student will be asked to evaluate their peers' contributions on a 3-point scale: Incomplete (0 / Student did not make any contribution to this aspect of the project), Satisfactory (1 / Student made a considerable contribution to this aspect), and Excellent (2 / Student made an excellent contribution to this aspect).

The students are given a form to evaluate their peers close to the deadline with their scores to other students from their teams on their contribution to overall team success. The final score under this component will be a geometric mean of all the scores received by the student. Peers are expected to justify their score. That means the students cannot just give a score (2, 1, or 0). Instead, they should also explain why they think their peer deserves this point – and no less and no more. For instance, one receiving a "0" score must have actively hindered the progress of the teamwork, at least for the student evaluating this teammate. This approach ensures a voice for each student. If a single student in the team is cornered and feels unsupported by their peers, they could make 0 points with justification, thus making the unsupportive peer's geometric mean get 0. We hypothesize that such a construct is expected to motivate fair contributions from students, prevent idle partners, and encourage collaboration with teammates.

Similarly, during the final day of the projects, all the students from other groups evaluate the demos on the same Incomplete (0), Satisfactory (1), and Excellent (2) scale. The final score under this component will be an arithmetic mean of all the scores received by the student. We anticipate that while the teammates will score each member differently, other students are more likely to grade all team members equally. However, the instructor will carefully and individually grade each member's contribution to ensure no freeloaders in the team. Each team's work is considered for a research publication, with corrections and enhancements from the instructor. The students will be able to voice their opinions of the group projects, peer learning activities, and overall learning experience through their faculty evaluation and questionnaires at the end of each semester, which will facilitate the annual review of the instructor. These additional measures ensure a continuous improvement to the team formation. Interested students may continue to work on their research papers with the instructor beyond their course timeline to refine their work for publication.

We will evaluate the overall success of our proposed approach through the semester-end anonymous student survey outcomes on faculty evaluation and student success. We will compare the results across the modules and prior years before the proposed system and during the iterations across semesters to ensure continuous progress and improvements.

I) Net Neutrality Debate and Content-Aware Networking

*The net neutrality regulations mandate that Internet Service Providers (ISPs) cannot discriminate on connectivity based on the nature of the application. Net neutrality ensures fair access to all the legal content to the end users, preventing the ISPs from blocking or throttling websites or prioritizing content that is paid a premium for. Such fair access is a crucial component in maintaining equal access to the websites. However, enterprises always try to push these regulations for their profits. Zero-rating offers are an example. Specific applications are bundled and offered for free or at a better-performing data rate. Some examples of offers are from MEO.pt in Portugal in 2017 and Vodafone in New Zealand. These preferential offerings may negatively impact other Internet data traffic, including critical web applications such as telehealth visits and tele-education. On the other hand, content-aware networking research focuses on leveraging the knowledge of the content to provide better access to critical content. For instance, what if these Internet "fast lanes" are offered for telehealth instead? However, their applicability in routing and scheduling data based on content and how they will violate net neutrality are questioned. This project will look into content-aware networking and how they can operate without compromising the net neutrality principles (or can they not?) An emulated application can be a plus.*

N) Federated network architectures

*This project looks into network communication mechanisms across multiple network domains. While classic network switches have both a data plane and a control plane in each of them, Software-Defined Networking (SDN) unifies them to have logically centralized control. However, such unified control and management is feasible only when a single entity (such as a company or university) owns and manages the entire network.*

*When multiple organizations want to coordinate their networks, the network communication cannot resemble such unified access and control, as centralized control in such environments will not make sense. Protected access to the networks, while sharing minimal control across the domains, is essential in such scenarios.*

*That is when federated networks come into play. These networks can span multiple organizations or multiple clouds. They can also function with SDN, providing a federated orchestration of controllers belonging to various network domains. Students understand and learn how network protocols scale beyond the data center level in this project. We have learned about data centers, enterprise networks, and the Internet. Here, we focus on somewhere in between - a network of networks that is not the Internet. But instead, a federated network. This group will also evaluate the current federated network architectures and the future trends.*

Listing 2. Two illustrative project ideas in Computer Networks from Fall 2023.

## 4 Discussion

Our project-based learning approach aims to build capacity in STEM education, specifically undergraduate computer science, by augmenting the computational capacities of the class/lab with students' devices working as a cluster for group projects. We envision fostering efficient, reusable mechanisms to formulate robust and self-sustaining student groups. We identified specific modules (Computer Networks, Computer and Network Security, and Distributed Systems) as the applications for this project, as these modules typically require more than one computational node for their physical implementation. However, the developed framework can be used for other computer science and engineering modules and other STEM disciplines in general. We aim to obtain feedback and adoption from other faculty for other CS modules to test the approach's applicability in a broader sense.

Several factors contribute to challenges in students' academic success. Supportive peer learning environments have been shown to reduce those barriers to academic excellence in marginalized communities (Tai et al., 2017). Therefore, we anticipate positive outcomes from fostering peer learning exercises in the class rather than having only the lecturer-centric traditional lectures, with an increased sense of belonging and peer mentoring across the student groups (Won et al., 2018). An inclusive classroom and peer learning may foster creative freedom among the students by providing a non-judgmental environment (Ballard et al., 2008). First-generation undergraduates have more barriers to entry into STEM research than those from academic families (Stebleton & Soria, 2013). This need for support emanates from the students being first in their families and homes to enter higher education and who face challenges in overcoming psychological issues caused by their educational programs, many times involving linguistic, disability, economic need, and health issues.

This project is a pilot for undergraduate CS classes with a large, diverse student population, requiring access to extensive distributed computational resources with limited availability. The instructor commits to offering a student-centric education through a place-based learning approach, with greater importance and respect to projects that contribute to the land and the local communities. The continuous feedback from the students throughout the courses and the semester-end surveys will allow us to develop a self-improving, reproducible model that can facilitate similar delivery across other CS classes, especially those modules that can benefit from hands-on programming and software development challenges, with a greater need for communication and collaboration across multiple computers forming a cluster for a realistic physical execution. We will evaluate how an inclusive classroom will benefit the students through our project-based learning approach with greater freedom in team performance. Combined with active learning approaches such as flipped learning, we anticipate the projects will form a crucial pillar in their education journey in the associated courses.

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# Development of a Training Strategy for Consulting Sales Engineers in New Technologies for Business Solutions through Andragogy

Laura Ramírez P[1], Andres Ramirez-Portilla[2]

[1] Centro de Investigación Pedagógica del Caribe, Universidad Pedagógica del Caribe, S.C., Cancún, México
[2] *Tecnologico de Monterrey, Escuela de Ingeniería y Ciencias, Ave. Eugenio Garza Sada 2501, Monterrey 64849, NL, Mexico*

Email: ramirez.laura@gmail.com, ramirez.andres@tec.mx

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**Abstract**

This paper delves into the strategic development of a training program tailored to empower Sales Engineers engaged in consultative technology sales. The focus of this initiative lies in integrating and mastering New Technologies for Business Solutions, with a pedagogical emphasis on the application of Andragogy. Acknowledging the unique learning characteristics of adult professionals, this strategy aims to optimize the acquisition and utilization of knowledge in the rapidly evolving landscape of technology-driven business solutions. The foundation of the training strategy draws heavily from the principles of Andragogy, highlighting the importance of self-directed learning and the integration of adult learners' rich experiences in the educational process. Furthermore, the rapid instructional design principles are incorporated to ensure a targeted and practical approach to skill development in consultative technology sales. The training modules are designed to be dynamic and interactive, integrating real-world case studies and simulations that mirror the complexities of consultative technology sales. By emphasizing hands-on experiences and collaborative learning methodologies, the strategy aims to facilitate immediate knowledge application within the professional context. Evaluation mechanisms within the program assess the impact on sales performance and the adept utilization of New Technologies for Business Solutions. The continuous improvement cycle is driven by feedback mechanisms and performance metrics, ensuring the ongoing relevance and effectiveness of the Andragogy-based training strategy. This paper contributes to the intersection of adult learning, sales training, and technological solutions for businesses, offering practical insights into the successful implementation of Andragogy to enhance the competencies of Sales Engineers in navigating and capitalizing on the opportunities presented by new technologies in the realm of consultative sales.

**Keywords:** Andragogy; Training Strategy; Educational Innovation; Higher Education; Professional Education

## 1 Introduction

This work develops a practical case and explains the principle of andragogy applied to professional education, specifically, in the technological and business area. Normally industry and teaching are not fields that are consciously mixed, however, every time a person enters a new job position, they must have openness and enough humility to learn what they do not know and apply what they already understand. This combination of experience and innovation leads the new worker to face new challenges. These challenges are not only based on meeting the expectations of the position you obtained, but also on balancing your work and personal life or meeting goals, but at the same time you must learn an entire portfolio of new concepts and products within the company.

Taking a real example of Sales Engineers in New Technologies, several points that will be developed throughout this document must be considered. It begins by explaining what andragogy is and its principles; It is defined as the art and science of helping adults learn. According to him, andragogy is based on a series of principles that recognize the unique characteristics of adult learners, such as their autonomy, accumulated experience, intrinsic motivation and task orientation. This perspective implies a more student-centered approach, where learning is facilitated through active participation, the relevance of content and the practical application of knowledge (Knowles, 1984).

This work develops a practical case and explains the principle of andragogy applied to the technological and business field. Normally, industry and education are not fields that are consciously mixed, but each time a person enters a new job position, he must have openness and enough humility to learn what he does not know and apply what he already understands; this combination of experience and innovation leads the new worker to face new challenges. These challenges are not only based on fulfilling the expectations of the position you have been given, but also on balancing your work and personal life or achieving goals, while at the same time learning a whole portfolio of new concepts and products within the company.

Taking a real example of Sales Engineers in New Technologies, several points need to be considered that will be developed throughout this document. Firstly, it explains what andragogy is and its principles; it is defined as the art and science of helping adults learn. According to him, andragogy is based on a set of principles that recognize the unique characteristics of adult learners, such as their autonomy, accumulated experience, intrinsic motivation and task orientation. This perspective implies a more learner-centered approach where learning is facilitated through active participation, relevance of content and practical application of knowledge (Knowles, 1984). Merriam emphasizes the importance of recognizing the differences between adult learning and that of children. His concept of andragogy focuses on lifelong learning and the link between theory and practice. They argue that andragogy implies a participatory and collaborative approach where adults are seen as co-creators of knowledge and self-directed learning is encouraged. He also emphasizes the importance of reflection and dialogue in the adult learning process (Merriam & Bierema, 2014). Considering these two definitions, andragogy is considered essential to organize the knowledge of adults, it is the science that helps to develop the idea of learning and teaches us to know how adults learn, as they can decide autonomously what, how and when to learn. To better understand the concept, a comparison table between andragogy and pedagogy is shown.

Table 1. Comparing andragogy versus pedagogy

| | **Andragogy** | **Pedagogy** |
|---|---|---|
| **Definition** | Art and science of helping adults learn, focusing on their autonomy, experience and intrinsic motivation (Knowles, 1984) | Educational approach focused on teaching children and adolescents, guided by an educator (Bruner, 1996) |
| **Characteristics** | • Self-directed learning<br>• Accumulated experience<br>• Task orientation<br>• Intrinsic motivation (Knowles, 1984) | • Educator-led instruction<br>• Emphasis on discipline and structure<br>• Development of cognitive and social skills (Bruner, 1996) |
| **Approach** | Participatory, collaborative and focused on the adult student (Merriam & Bierema, 2014) | Based on the authority of the educator and the transmission of knowledge (Bruner, 1996) |

By understanding the six key principles of andragogy, we can build a strong foundation for designing effective adult learning programs and applying them in a variety of business settings. These principles emphasize learner autonomy, where adults take charge of their learning journey, driven by a desire to understand the benefits of acquiring new skills and knowledge (Knowles, 1984). Their extensive prior experience becomes a valuable resource (Knowles, 1984) and should be recognized in program design. Adults are most motivated by learning that directly addresses their job needs and helps them solve problems (Knowles, 1984). Intrinsic factors such as self-improvement and personal satisfaction drive their motivation more than external rewards (Knowles, 1984). Recognizing the diverse learning styles, experiences, and individual needs of adult learners is critical to effective teaching (Merriam & Bierema, 2014). Finally, real-life application and practical relevance are key to successful adult learning, as adults strive for continuous learning to reach their full potential (Merriam & Bierema, 2014).

## 2 Development

Based on this concept and principles then you can begin to think about what it takes to create an adult learning program, specifically for Consulting Sales Engineers in New Technologies. When you need to create a course with a specific structure, you must take into account the different phases that the content goes through until it is finished. The set of these phases is called instructional design. Getting involved in this process requires time, dedication, and effort from a team of professionals who cover different profiles within the company and who are willing to transmit their knowledge. Understand the concept of instructional design as the systematic and multidisciplinary process of planning, developing, evaluating, and managing effective and efficient educational solutions to achieve the objective of facilitating meaningful and lasting learning in students (Morrison, Ross & Kemp, 2013). Understanding the principles of adult learning (andragogy) provides the foundation for creating engaging and effective training programs for Consulting Sales Engineers (CSEs) in new technologies. Andragogy emphasizes learner autonomy, the use of prior experience, and a focus on practical application-all of which are critical for adult learners. However, creating a structured learning experience requires a systematic approach. This is where Instructional Design (ID) comes in. ID is the multi-step process of planning, developing, delivering, and evaluating instructional programs. It ensures efficient knowledge transfer and sustainable learning outcomes.

Although there are different approaches to train service engineer, it is common to see in industry six key steps that are used to create a structured approach for training continuous service engineers (CSEs) on new technologies. This approach aligns with the ASSURE model (Heinich 2002). It begins with a Needs Assessment, identifying the specific knowledge gaps and desired skills the CSEs need to acquire. Next, Design Objectives translate these needs into clear, measurable goals for the training program. Selecting Strategies focuses on choosing the most effective teaching methods, like interactive workshops or simulations, to achieve these objectives. Developing Materials involves creating engaging resources like e-learning modules or case studies, potentially leveraging existing corporate resources. Implementation and Delivery ensure effective program rollout, considering adult learning styles to foster a positive learning environment. Finally, Evaluation and Review emphasize ongoing assessment and feedback to improve the training program's effectiveness continuously. In this case, we planned to base the corporate training design on the ASSURE model.

The ASSURE model, developed by Heinich (2002), offers a structured yet flexible framework for crafting impactful learning experiences. This model, grounded in constructivism principles, prioritizes active student participation and the strategic use of technology. Imagine the ASSURE model as a roadmap, guiding instructional designers through a series of steps to ensure the creation of effective and engaging learning environments. The initial steps of the ASSURE model serve as a practical guide for successful learning. The first step, Analyze Learners, is all about getting to know the students. This involves identifying learner characteristics, needs, learning styles, and prior knowledge. By tailoring instruction to this specific audience, educators can ensure the content resonates with the students and lays a strong foundation for learning. Following this, the Establish Objectives step guides the development of clear and concise learning objectives.

These objectives outline the specific knowledge and skills students should gain from the instruction. Having a clear understanding of the desired outcomes allows educators to design the remaining steps of the model effectively. With a solid grasp of the learners and the desired learning outcomes, the ASSURE model begins crafting the actual learning experience. The Select Methods, Media, and Materials step involves choosing the most appropriate teaching strategies. This could include anything from lectures and discussions to simulations and games. Here, instructional designers select the most suitable technological resources and support materials to achieve the established objectives. The Utilize Media and Materials step focuses on seamlessly integrating these chosen resources into the instructional design. This ensures alignment with goals, student needs, and the overall flow of the learning experience.

The ASSURE model is not a one-time solution but a dynamic process. The Require Learner Participation step emphasizes the importance of activities that actively engage students in the learning process. By fostering participation and collaboration, educators can enhance student understanding and retention of the material. Finally, the model concludes with the Evaluate and Revise step. This step involves ongoing evaluation of the instruction's effectiveness. Through assessments and feedback mechanisms, educators can identify areas for improvement and continuously refine the teaching and learning experience for future iterations. By following these steps, the ASSURE model empowers educators to create meaningful and engaging learning environments for students (Heinich, 2002; Smaldino, Lowther, & Russell, 2019).

# 3 Program Phases

In this section we describe the Design Sprint approach of the program proposed which has shown to be a phased approach to project success. The program is based on four main phases, with Phase 3 being the backbone of the program and learning as it applies the ASSURE model to engage future students (Erickson & Yorks, 2017). The Design Sprint methodology breaks the project development process into four distinct phases, each with its own focus and deliverables.

**Phase 1**: *Understand lays the foundation for the entire project.*

This phase is dedicated to gaining a deep understanding of the challenge at hand. By consulting with experts, the team gathers diverse perspectives and insights. Deliverables for this phase include a project management and planning report that outlines key milestones, and a comprehensive research report. This research combines secondary research, leveraging existing internal documentation of past experiences, with primary research, obtained by interviewing leaders from other organizations or universities to identify best practices.

**Phase 2**: *Monitor shifts the focus to the user and their specific needs.*

Here, the team conducts in-depth interviews with executives and facilitates a focus group to gather qualitative data. In addition, interviews with current internal leaders provide valuable insight into the skills required for their roles and any skill gaps within the team. This information culminates in qualitative and quantitative findings report.

**Phase 3**: *Think Up delves into the creative process of model development and program design.*

The team works together to configure a talent development model. This collaborative effort includes brainstorming sessions ("Ideation") to explore initial research and archetypes, followed by a period of "Divergence & Convergence" where ideas are expanded and ultimately refined into a cohesive program design. The final deliverable of this phase is a talent development model.

**Phase 4**: *Validate focuses on refining and finalizing the program approach.*

A focus group is convened to discuss the proposed program, and based on their feedback, the team prepares a final report and visual materials that effectively present the program. Finally, this phase concludes with a presentation to stakeholders that summarizes the project's findings and recommendations.

# 4 Talent Development Model

To put both the methodology and the phases into practice, the following proposal is considered. The strategy of using motivational phases for the Leadership Program is based on the idea that leaders seek to have a clear purpose in mind, which generally involves mastering or achieving certain knowledge in a field to later have the freedom and autonomy to use that knowledge to achieve their goals. For this reason, we propose the following axes for the program (Kouzes & Posner, 2017; Northouse, 2019):

- *Knowledge*: Strive to be better at everything you do, become an expert.
- *Purpose*: Everything you do has a personal and professional purpose and impact.
- *Autonomy*: Decide your own destiny and how you want to develop in life and career.

Based on these axes, we think about the background to follow the program, but the activities, and these are divided by type.

- *Baseline*: Throughout the program, participants will engage in various activities that follow a logical sequence. These activities will allow them to apply the knowledge and skills they have previously acquired.
- *Bonus*: Participants choose activities based on their preferences and aspirations. These activities earn points that can be exchanged for reward-type activities.
- *Reward*: Reward activities have a participant limit. Participants are selected based on the accumulation of bonus points and the submission of a request activity.

# 5 Training Path

In response to the company's requirements regarding talent development, the training path was designed to prioritize the three primary axes previously described: purpose, knowledge and autonomy; with activities tailored to specific types (Kouzes & Posner, 2017; Northouse, 2019).

## 5.1 Purpose

This program offers a three-month positive psychology course designed to equip managers as the company's "positive ambassadors." Through a series of modules, the course aims to establish a positive mindset within managers. Topics will delve into the foundations of positive psychology, exploring concepts such as overcoming adversity, goal setting, and fostering strong relationships with colleagues. The curriculum includes an introduction to positive psychology, followed by a deep dive into its various branches. Participants will learn practical techniques for positive transformation, including the power of positive feedback and strategies for maintaining overall well-being. By the conclusion of the program, managers will be equipped with the tools and knowledge to cultivate a positive and thriving work environment. This aspect of the "purpose" axis can be reinforced through various techniques, tools, and initiatives, including the following:

- ***Building Connections Through Film: Movie Night for Staff Integration***

Offers a unique opportunity to foster coexistence and learning among colleagues in a relaxed setting. This activity goes beyond simple entertainment by encouraging critical analysis of ethical issues presented in a film. The chosen movie will showcase a compelling narrative that confronts viewers with ethical dilemmas. Following the film, a structured discussion facilitated by a designated leader will guide participants through a case-study method. This method involves collaboratively analyzing the scenario in the film by:

- Identifying key facts and the core problems faced by the characters.
- Brainstorming potential solutions to these problems, weighing the advantages and disadvantages of each.
- Discussing the implementation of the chosen solution and its potential outcomes.

By openly discussing complex ethical dilemmas in the context of a shared cinematic experience, movie night facilitates learning and bonding among colleagues. Reflecting on the challenges and navigating solutions together fosters a sense of common understanding and strengthens team dynamics.

- ***Sharing Knowledge Across Locations: IntraForums***

Utilizes video conferencing technology to bridge the gap between geographically dispersed teams, promoting global corporate knowledge. These sessions connect teams from different company locations who share similar areas of expertise. The core objective is to share and enrich best practices, fostering a spirit of collaboration and continuous improvement.

During an IntraForum session, managers from different locations can present a current challenge they are facing within their teams. By sharing these real-world situations, colleagues can gain valuable insights into how similar situations are handled in other locations. This exchange allows for the dissemination of best practices, equipping participants with alternative approaches and solutions that may be applicable to their own teams.

To solidify the learning outcomes, the session concludes by highlighting the three most valuable takeaways identified during the discussion. These key points can then be implemented in each participating location, driving continuous improvement and knowledge sharing across the entire company.

## 5.2 Knowledge

The knowledge axis in the training path is designed to enhance the professional and technical skills of participants, preparing them to take on leadership roles and significantly contribute to innovation within the company. Through interactive workshops, immersions in high-tech environments, and programs that foster creativity and entrepreneurship, participants will acquire essential competencies that enable them to excel in their respective fields and adapt to the rapidly changing business landscape. The "knowledge" axis can be effectively developed through a range of activities and methodologies, such as the ones listed below:

- ***Building Your Brand and Voice: Personal Marketing and Public Speaking Workshop***

This comprehensive workshop equips participants with the skills and confidence to establish themselves as strong leaders and effective communicators. Targeting future leaders, the program focuses on honing personal branding and public speaking abilities. The workshop delves into the "6 Ps of personal marketing," a framework for building a strong individual brand. Participants will gain valuable insights into cultivating essential personal skills, including effective communication and interpersonal development. Mastering both verbal and non-verbal language is explored, empowering participants to deliver impactful messages.

Leadership development is fostered through engaging team games that identify individual leadership styles. Additionally, the workshop covers a range of practical skills, including public speaking techniques. Participants will receive impromptu speaking exercises, honing their ability to think on their feet and deliver clear, concise messages. Building on this foundation, sales techniques are explored through role-playing exercises, allowing participants to practice persuasive communication in a realistic setting.

The program also emphasizes the power of storytelling, equipping participants with the ability to craft and deliver impactful narratives. Networking strategies for building strong professional relationships are explored, preparing participants to navigate professional settings with confidence. To solidify the learning experience, the workshop culminates in a final presentation in the style of a TED Talk. This allows participants to showcase their newly acquired skills by delivering a 3–5-minute speech on a chosen topic, putting their personal brand and communication abilities on display.

- **Silicon Valley Immersion Tour: A Journey into Innovation**

The Silicon Valley Immersion Tour offers a unique opportunity for company leaders to delve into the heart of innovation. This immersive experience is specifically designed to connect participants with the latest trends and disruptive technologies shaping the industry. To participate, managers are invited to submit a one-minute video showcasing a project they envision implementing within the company. This selection process ensures that the learning experience aligns with individual and company goals.

The program itself is an immersive journey into the heart of Silicon Valley. Participants will have access to exclusive experiences, connecting with industry leaders, entrepreneurs, and thought provokers at the forefront of technological advancement. Following this intensive exposure to the cutting-edge, participants are given an additional five days to translate their learnings into actionable plans. During this structured period, they will define a clear strategy for leveraging the acquired knowledge to create positive impact within their company. By fostering firsthand exposure to the ever-evolving landscape of technology, the Silicon Valley Immersion Tour equips participants with the inspiration and tools to drive innovation and propel the company forward.

- ***Igniting Intrapreneurship: Spin-Offs Program***

This program aims to unleash the entrepreneurial spirit within the company by fostering a culture of intrapreneurship. The Spin-Offs competition provides a platform for employees to showcase their creativity and develop innovative digital solutions. The program begins with the presentation of clearly defined challenges that the company seeks to address. Following this, teams are formed, uniting individuals with diverse skillsets and perspectives. These teams then embark on a collaborative journey, brainstorming, exploring, and ultimately developing solutions to the presented challenges. This collaborative process culminates in the creation of well-defined projects that address the needs of the company.

The final stage of the program involves a "pitch" session, where each team presents their proposed digital solution to a panel of judges. The three most compelling and well-executed projects are then awarded recognition. Selection criteria focus on the degree of project implementation, alignment with company strategy, and the innovative and disruptive nature of the proposed solution. By encouraging intrapreneurship and empowering employees to become innovators, the Spin-Offs program fosters a dynamic and creative environment, leading to the development of new digital solutions that contribute to the company's continued success.

## 5.3 Autonomy

The autonomy axis focuses on empowering participants to take control of their professional and personal development. Through immersive experiences and mutual learning programs, a comprehensive understanding of the company's operations is promoted, fostering a culture of collaboration and continuous improvement. This approach allows participants to develop a holistic business perspective, enhance their decision-making skills, and effectively contribute to the organization's strategic objectives. To foster autonomy, the program incorporates diverse strategies and practices, including but not limited to the following:

- ***Fostering Professional Growth: "You Choose" Week.***

The "You Choose" Week program empowers participants to take charge of their professional development. By selecting a department, area, or business unit of interest, they gain firsthand experience for one week. This immersive experience broadens their knowledge base, fosters professional development, and provides a deeper understanding of the company's structure and strategy.

After choosing their area of interest, participants dive into a one-week rotation. This immersive experience allows them to shadow colleagues, observe workflows, and gain practical insights into daily operations. To maximize learning, participants will be actively involved in departmental activities and projects whenever possible. To solidify their experience, participants will then engage in a self-reflection exercise prompted by specific questions to help them analyse their learnings.

• What did you learn in the area you rotated to? This prompts participants to identify key takeaways and knowledge gained during the rotation.
• What aspects of the area did you find most engaging? This question allows participants to identify areas of personal interest and potential career paths.
• What would you suggest improving the area's operations? This encourages participants to offer fresh perspectives and identify areas for potential optimization.

By actively participating in the "You Choose" Week program, postgraduate participants gain valuable insights into various aspects of the company, empowering them to make informed career decisions and contribute their talents to the area that best aligns with their professional aspirations.

- ***Expanding Expertise Through Inverse Shadowing***

The Inverse Shadowing program offers professionals a unique opportunity to gain a comprehensive understanding of the company's value chain. This program fosters a collaborative learning environment where participants can broaden their knowledge base and develop a holistic perspective of the company's operations. (Smith & Johnson, 2018; Brown, 2020).

The Inverse Shadowing program offers a unique twist on traditional shadowing. Participants gain a holistic view of the company by observing managers from various departments, but the learning goes both ways. Participants not only observe daily routines and decision-making, but also provide constructive feedback on the manager's communication, leadership, and potential areas for improvement. This reciprocal exchange fosters a collaborative learning environment where both parties gain valuable insights. Sessions are strategically planned to coincide with meetings or activities offering significant learning value, ensuring participants gain practical exposure to essential aspects of the manager's role. Ultimately, Inverse Shadowing empowers professionals with a global understanding of the company's value chain, leading to better decision-making and stronger collaboration across departments.

- ***Sharpen Your Social Edge: Building Emotional Intelligence for Managers***

This program provides managers with the emotional intelligence (EQ) skills needed to excel in social interactions. Through interactive workshops led by an EQ expert, participants gain insights into key EQ dimensions: self-awareness, self-regulation, social awareness, relationship management, and motivation. Real-world scenarios and case studies relevant to managers help them apply learned principles to daily situations, navigate complex interactions, and build stronger relationships. The program incorporates interaction with individuals both inside and outside the company, fostering a nuanced understanding of interpersonal dynamics. By enhancing their social intelligence, managers create a more positive work environment, motivate teams, and achieve superior performance.

# 6 Results

Evaluating the impact of a training program is not just a step in the employee development process, it's a crucial one. It's through this evaluation that organizations can adjust and modify content to meet their goals and needs. Reliable assessment of a program's results is essential. This is where training metrics, also known as training KPIs, step in. They are not just tools, but the key to gaining an accurate view of the effectiveness and success of training programs (Noe, 2016; Phillips & Phillips, 2017).

In this evaluation, we focused on a group of 30 students and used several key training indicators to measure their progress and engagement with the course. The first metric, completion rate, measures the percentage of students who complete a course or training program compared to the total number of students enrolled. This rate is an essential indicator of the effectiveness and commitment of the participants to the program. The formula for this training metric is as follows Completion Rate = (Number of Participants / Total Enrolled) * 100. For this group, the completion rate was calculated as (27/30) * 100 = 90%. A high completion rate not only indicates strong participant engagement but also reassures you about the satisfaction of the participants with the course content and delivery. Conversely, a low completion rate may indicate problems with the relevance, difficulty, or accessibility of the course, and the need for additional support from the training team.

Attendance measures the percentage of scheduled training sessions that employees attend, providing crucial insight into their level of engagement and commitment. The formula for calculating this index is attendance rate = (attendees/sessions) * 100. For the group of 27 participants in 10 sessions, the total possible attendance was 270 (27 people x 10 sessions). The actual total attendance was 252, resulting in an attendance rate of (252/270) x 100 ≈ 93.33%. A high attendance rate is not just a number, it's a testament to the participants' active involvement and commitment to the training program. However, consistently low attendance may indicate scheduling conflicts, lack of interest, or dissatisfaction with the program, highlighting the need for further evaluation and improvement.

# 7 Conclusion

Training indicators or metrics are essential for evaluating training programs' success and impact. They provide concrete data that enables professionals, trainers, and employees to understand the effectiveness of their training efforts. The data provided by training metrics is not just numbers, they are the reassurance that your investments in training are justified. This ensures that training programs deliver appropriate performance and value to the organization, making you feel more confident in your training investments. Training metrics enable organizations to measure the performance of individuals and teams before, during, and after training. By assessing skill development, knowledge retention, and behavior change, managers can determine the impact of training on job performance.

Training metrics provide valuable feedback that supports continuous improvement efforts. Organizations can analyze trends, identify strengths and areas for improvement, and implement targeted interventions to enhance training strategies and maximize their effectiveness. By using training metrics, organizations can optimize resource allocation. This includes prioritizing initiatives that deliver the highest return on investment and ensuring the efficient use of time, money, and effort to support strategic priorities while keeping costs stable. In industries with stringent regulatory requirements, training metrics are not just numbers, they are the security blanket that ensures your employees are receiving the necessary compliance training. Tracking completion rates, quality control, and mastery of compliance training helps organizations mitigate risk and avoid costly penalties, making you feel more at ease with compliance training.

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# Developing a Chatbot for Process Modelling Learning: contributions for active learning in engineering education

Erik T. Lopes[1], Diana Mesquita[2], Rui M. Lima[1]

[1] Algoritmi Research Centre/LASI, 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, Portugal

Email: erik.lopes05@gmail.com, dmesquita@ucp.pt, rml@dps.uminho.pt

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**Abstract**

Technological advancements such as generative artificial intelligence (AI) chatbots have gained popularity, partly due to their ability to provide iterative access to extensive information. This has impacted the education field, introducing new opportunities and challenges in learning, teaching, and assessment. This article intends to present the development and deployment of a chatbot designed to foster students' learning regarding process modelling and Business Process Model and Notation (BPMN). Developed with a low-code tool from the Microsoft suite, this approach for building chatbots may be replicable in other contexts of higher education. This is an exploratory study with 18 students enrolled in a Master's Program in Engineering and Operations Management. Moreover, 6 professionals with experience in using BPMN used the ChatBot and gave an additional and complementary perspective from an expert point of view. The main objective is to evaluate the effectiveness of the ChatBot to mimic real-world interactions and make a contribution to the learning process. Through this exploration, the article aims to discuss potential uses of the chatbot, exploring the development steps, users' feedback, limitations, and opportunities for enhancement. This work underscores how emerging technologies facilitate the swift creation of specialized bots for diverse applications, sidestepping the need for intricate programming expertise. More than just enhancing student engagement by encouraging inquiry and the use of AI tools, the use of chatbots has the potential to significantly lighten the teaching load, a cited barrier in the adoption of active learning.

**Keywords**: Active Learning; Engineering Education; Process Modelling; Chatbot.

## 1 Introduction

Active learning approaches are an area of significant study that has been gaining more relevance in recent years. There are various approaches, each offering unique advantages and challenges, but overall, students gain more autonomy while teachers transition into roles more focused on supporting the learning process and less as transmitters of knowledge (Das Neves et al., 2021). Numerous studies indicate positive results from integrating active learning with other approaches such as project management and gamification (Freeman et al., 2014; Lopes & Aquere, 2021; Pereira et al., 2018; Theobald et al., 2020). Potential gains from its application include increased motivation, better integration of theory and practice, and the development of transversal communication skills (Das Neves et al., 2021; Lopes et al., 2021). However, there are challenges related to student engagement, students' insecurities about their autonomy, and an increased workload (Das Neves et al., 2021), with communication being a critical issue (Aquere et al., 2012). Furthermore, for proper application, teachers need to develop skills such as teamwork, empathy, feedback, and use of new technologies (Das Neves et al., 2021), with evidence linking teacher participation in training and research on the topic to the application of active learning in their classes (Lima et al., 2024).

Moreover, there is a rise in studies related to the education of skills demanded by Industry 4.0, termed by some authors as Education 4.0 (González-pérez & Ramírez-montoya, 2022; Souza & Debs, 2024). Much of this research focuses on engineering education and often involves technologies like artificial intelligence (AI), augmented reality, the Internet of Things, robotics, and virtual reality (Souza & Debs, 2024). In this context, simulations are one approach that has potential to enhance student experiences and develop skills such as managing large volumes of data (Lima et al., 2023). Further, research suggests that blended learning, e-learning, and gamification are the most effective methodologies for developing concepts of Education 4.0 (Souza & Debs, 2024).

Specifically, chatbots have gained more relevance in recent years. Their main uses are identified in higher education, particularly in the fields of social science, computer science, and engineering (Lins et al., 2023; Meloni et al., 2023; Ramandanis & Xinogalos, 2023a). They can take on roles of supporting teachers, assisting students, or even handling administrative activities (Ramandanis & Xinogalos, 2023b). However, developing these conversational agents involves several steps (Ramandanis & Xinogalos, 2023a), and it's important to allow flexibility so the bots can be configured without the need for programming skills (Rooein et al., 2022). Other challenges include user acceptance, the need for educator training, and ensuring all students have access to technology (Ramandanis & Xinogalos, 2023b). Nonetheless, their use can complement traditional learning methods by providing a unique learning opportunity (Rooein et al., 2022).

Thus, this paper aims to present the development and application of a chatbot for supporting teaching and learning of Business Process Model and Notation (BPMN) and process modelling, based on a case study in a master's class in engineering and operations management. The paper details the step-by-step process used, user perceptions, potential advantages and challenges, and future research to enable the use of this tool by teachers without a technology background.

# 2 Methodological Approach

This paper is an exploratory case study applied in a master's course in engineering and operations management for teaching process modelling in BPMN. 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. In their literature review, Ramandanis and Xinogalos (Ramandanis & Xinogalos, 2023a) suggest an approach with 12 main steps, along with various recommendations and best practices identified from the analysis of 73 studies related to the development of educational chatbots. However, the authors themselves emphasize that each researcher should adapt the stages and methods they prefer, according to their context. Therefore, since one of the goals of this investigation is to develop chatbots in a practical manner, the mentioned approach was simplified to just six steps: initial analysis, definition of characteristics, design, implementation, testing, and evaluation.

# 3 Chatbot Development and Application

## 3.1 Initial Analysis

The initial analysis aims to gather information and analyse both the tools for developing the chatbot and the context in which it will be applied. This stage includes gathering technical and financial requirements for software use (e.g., licenses), examples of chatbots developed in the literature, and characteristics of the course to be implemented, such as the number of students, classroom infrastructure, study topics, and main challenges.

In the context of developing this paper, the authors sought tools that were available at no cost and that required reduced development time, making replication feasible for teachers without technical knowledge in computing. Although there are generative AI solutions that allow for the automatic training of models using a reference document, their use would require individual licensing for each student, which would be impractical. Therefore, the choice was made to use Power Virtual Agents, a tool included in the Microsoft suite that allows for the modelling of workflows, incorporates AI Copilot, and is accessible through Microsoft Teams, to this university.

Regarding the course, the application was directed to the master's class in Production Management Processes. This course is part of the master's in industrial and systems engineering, with about 35 students, and covers topics such as process modelling, bill of materials, and production process management.

## 3.2 Definition of Characteristics

The definition of characteristics is the stage where the initial scope of the chatbot is finalized. Key aspects to define include the purpose and role of the application, the conversation flows, the tools the chatbot will use, and the training approach to be adopted.

As mentioned earlier, Microsoft Power Virtual Agents was chosen for its ease of use, availability, and potential replication in other contexts. Based on the curriculum analysis, it was determined that the chatbot's objective would be to simulate the process of a process mapping interview. To this end, it will assume the role of an employee at a recycling company and must answer students' inquiries in a way that allows them to actively practice developing questions and to gather information, a necessary skill for process modelling. Thus, the chatbot will complement the students' training and assist the teacher by enabling a role-play strategy with a large class without requiring more than one class session. For this purpose, the chatbot will provide general instructions, textual responses, and links to supplementary materials. At the end, it will present the modelled process so that students can verify their responses.

## 3.3 Design

At this stage, the goal is to design the chatbot by defining the educational material to be used, the robot's interactions, expected behaviours, and vocabulary, among other elements. Necessary adaptations are also made to the previously defined characteristics to ensure coherence in the solution being developed.

Following the definitions from the previous stage, the authors chose a process related to waste recycling to be modelled by the students. As a result, a process model was created along with a document describing the process, which would be used for training the model. Subsequently, a diagram was developed outlining the conversation flows, defining loops, supplementary materials, and features to be incorporated. To simplify implementation, a series of predefined questions were established that guide the robot's behaviour, although they limit user interactions. Table 1 presents the main features planned for the prototype.

Table 1. Chatbot design

| **Features** | **Description** |
|---|---|
| Presentation | The chatbot should start the interaction by introducing the project, explaining its objectives, and any limitations. If possible, it should ask the user to select their preferred language for communication. |
| Introduction | The bot should introduce itself by detailing its role and the context within the company. It should then provide users with various options to guide the next steps of the interaction. |
| Mapping Process Tips | The bot should offer general tips on process mapping, which are generated using artificial intelligence. These tips should aim to provide foundational advice and encourage best practices. |

| Features | Description |
|---|---|
| Indicating Supplementary Materials | The bot should provide links to the class LMS, websites for additional resources, and suggest contacting the instructor for more personalized guidance. |
| Describing the Recycling Process | The bot should open a series of options for user interaction, such as an overview of the process, stakeholders involved, activities, and triggers. It should provide answers progressively as the user interacts with each option. If the bot lacks an answer, it should suggest that the user speaks with another employee or the instructor for more information. |
| Closure | The bot should thank the user for their interaction and provide the results of the exercise, including an image of the BPMN process and a complete description (from the file used in its training). It should also present a feedback survey and contact information from the developers. |
| General Characteristics | The bot should be programmed with user-friendly language, perform validations with the user, and accept free-text commands for actions such as restart, report an error, and end the conversation. |

## 3.4 Implementation

The implementation stage involves developing the chatbot using the chosen tool to produce a functional version. This phase typically requires knowledge of programming tools and may necessitate the use of other technologies as challenges arise. It also includes training the robot, where various techniques such as predefined questions and machine learning can be employed.

In the context of this development, the features listed in Table 1 were implemented. Additionally, triggers were added for free-form inputs for words like "restart," "bye," and "end" to enhance usability. Concurrently, artificial intelligence was used to generate an image of Lateco, the name given to the bot. Figure 1 illustrates the implementation process and the final version of the prototype.

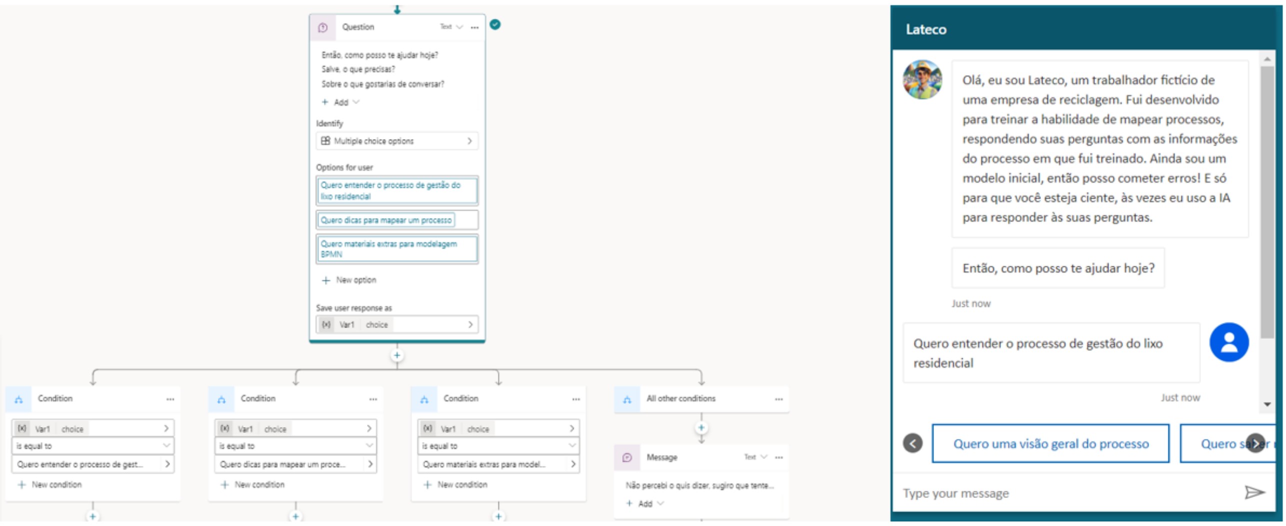


Figure 1. Development and Prototype of the Chatbot.

## 3.5 Testing

Testing is the phase where the current version of the chatbot is verified, and it can be conducted with different stakeholders, such as students, experts, and teachers. It is crucial in this stage to have clear guidelines for use and to collect data for evaluation and the development of improvements.

In the case of Lateco, testing was conducted in two ways: synchronously with students and asynchronously with industry professionals. The synchronous session involved a process modelling exercise where students were required to interview the chatbot and map out the process based on the information received, lasting approximately 1 hour and 15 minutes. The lead developer was present during the session to provide guidance, answer questions, and identify problems and difficulties experienced by the students. The asynchronous test involved distributing the chatbot's access link and guidelines to industry professionals experienced in process modelling, to gather insights from individuals who have modelled processes using traditional tools. In total, about 30 people tested the chatbot.

### 3.6 Evaluation

Finally, evaluation involves collecting and analysing feedback from all stakeholders involved in the use and development of the chatbot. Methods such as interviews, questionnaires, or even student performance can be used for this purpose. Criteria that might be assessed include the accuracy of the responses, usability, and fulfilment of expectations.

For this implementation, a questionnaire was set up to be sent by the bot at the end of the interaction, aiming to characterise the user's profile (whether a student or industry professional), familiarity with using chatbots, prior knowledge of process modelling, and to analyse the bot's use. About 30 people used the bot, with 24 responding to the evaluation questionnaire. Additionally, some unstructured interviews were conducted with volunteer participants who engaged with the initiative and expressed interest in providing more in-depth feedback than what the questionnaire could capture. In the next section, the key findings will be presented and discussed.

## 4 Results and Discussion

The questionnaire described was answered by 24 participants, including 18 master's students and 6 industry professionals. Among the master's students, 6 reported having basic knowledge of process modelling, 7 claimed intermediate knowledge, and 5 were first-time learners during the theoretical lessons of the course. In the case of industry professionals, 5 asserted having advanced process modelling knowledge, and 1 had basic knowledge.

Regarding familiarity with using chatbots, students and professionals had average scores of 2.78 and 4.33 respectively on a scale of 1 to 5, where 1 signifies "never use" and 5 means "use regularly." Concerning the use of the Lateco chatbot, participants rated various statements on a scale of 1 to 5, which are presented in Figure 2.

From the graph, we can see that the users' experience was predominantly positive. The first statement was better received by the students, possibly because they have less experience with process mapping, while the professionals did not consider it a relevant tool to improve question-making. Additionally, the fact that the application had preset, suggested questions may have limited the users' experience in formulating their own questions. On the other hand, the second statement suggests that the professionals better recognize the potential of this approach compared to traditional methods, perhaps due to their prior experience learning BPMN in a conventional way, with all fully agreeing that using the tool is preferable to receiving a question in text form. Subsequently, both groups agreed that the chatbot assists in learning and practicing process modelling. However, the ratings on the chatbot's ability to simulate the interview process were the lowest, mainly due to the limitations in questions and responses of the current version. Several participants suggested improvements related to interaction, allowing for more assertive free-text conversations. Finally, the overall experience of the participants was satisfactory, but again with lower ratings from the professionals. This may be related to their greater familiarity with using chatbots, coupled with expectations for a more advanced model.

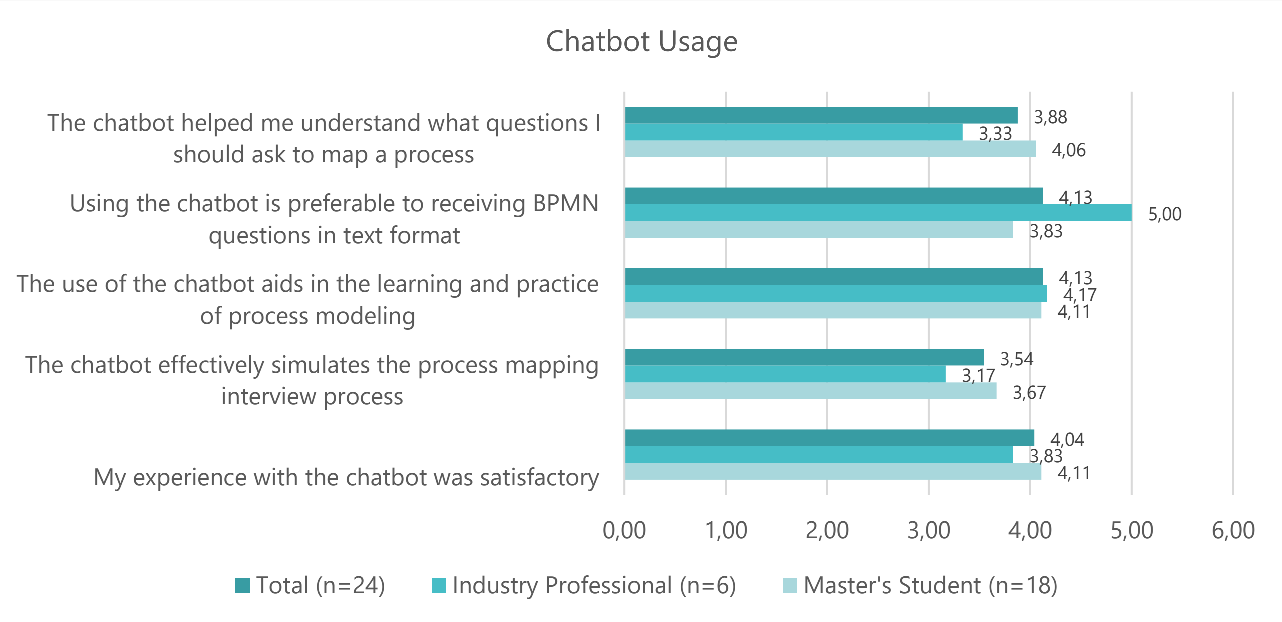


Figure 2. Results Related to the Use of the Chatbot.

In order to better explore the results and learnings, the upcoming sections will summarize the positive aspects, negatives, and suggested improvements indicated by the participants.

## 4.1 Positive and Negative Points

In summary, the positive aspects of using the chatbot focused on its ability to clarify concepts quickly and objectively, supporting learning in an intuitive and accessible manner. However, criticisms primarily concern the limited nature of interactions and the need for a richer and more detailed experience, suggesting opportunities for improvement in the design of responses and the overall usability of the system. Table 2 summarizes the main findings from the questionnaire and interviews.

Table 2. Positive and Negative Points.

| **Positive** | **Negative** |
| --- | --- |
| • Clarifying and Objective: The chatbot is perceived as a tool that clarifies doubts and presents concepts objectively, facilitating learning and understanding of the modelling process.<br>• Intuitive and Easy to Understand: The chatbot's interface is considered intuitive, making the user experience simple and accessible, even for those with less technological experience.<br>• Support in the Learning Process: Participants value the support provided by the chatbot in the practice of process modelling, helping to perceive the processes more clearly and contributing to projects and studies.<br>• Quick Responses: The speed with which the chatbot responds is seen as a positive point, allowing for more dynamic and efficient learning. | • Predefined Responses and Limitations: A recurring criticism was the perception that the chatbot offers many predefined responses, limiting interaction. This can lead to a less personalized.<br>• Interaction Limitations: Users reported difficulties in interacting freely with the chatbot, missing more fluid navigation and responses adaptable to their specific queries.<br>• Lack of Depth and Details: Some participants found the chatbot "insufficiently detailed" and still in an early stage, suggesting that there is room for expansion in terms of content and detailing of the information provided.<br>• User Experience Needs Improvement: There was a need for improvements in the user experience, such as a basic script to guide interactions and avoid the feeling of being "stuck" to listed questions, which could make the interaction more natural and engaging. |

Previous research indicates that some students may not like experiences with guided paths, preferring to explore topics more freely, as well as the need for human-like and fluent conversations (Ramandanis &

Xinogalos, 2023b; Rooein et al., 2022). Some suggestions for better interaction design include adding better conversational traits, response speed, and acceptance of oral messages as inputs (Ramandanis & Xinogalos, 2023a), points that could be explored in future versions. Moreover, it is interesting to allow other response formats beyond text messages (Ramandanis & Xinogalos, 2023b). These enhancements aim to refine the chatbot's capabilities to better meet the needs and expectations of its users, making the learning process more engaging and effectively integrated into the educational framework.

### 4.2 Suggestions for Improvements

The suggestions for improvements to the chatbot and its use in the teaching and practice of process modelling, based on participant feedback, focus on enhancing both the quality of interactions and the richness of content. Here is a summary of the main suggestions mentioned:

- Reducing Limitations in Responses: There is a desire for fewer restrictions in the responses provided by the chatbot, suggesting a need for greater autonomy and the ability to offer more personalized and adaptive conversational style responses to user queries.
- Improving the Quality of Information: Participants highlighted the importance of reducing errors and enhancing the quality of the information provided, indicating that accuracy and reliability are essential for an effective educational resource.
- Advancements in Usability: Suggestions include improvements to the chatbot interface, such as implementing question options in a message format instead of drop-down menus, aiming for a more natural and interactive user experience.
- Interaction with Different Levels of Interlocutors: The possibility of interacting with different profiles within the modelling process, such as analysts and coordinators, was suggested. This could enrich learning by exposing users to varied perspectives within the same context.
- Integration with Specialized Documentation: The idea of feeding the chatbot with specialized documentation and structuring an integrated search engine was mentioned as a way to expand the reach and depth of content available to users.
- Personalization of Learning: It was suggested that the chatbot could offer personalized learning paths based on the needs and knowledge level of users, enhancing the pedagogical effectiveness of the tool.

In summary, the suggestions for improvements involve increasing flexibility in interactions, ensuring information accuracy, enhancing usability, and providing a richer and more personalized learning experience. These improvements aim not only to make the chatbot a more efficient tool for teaching process modelling but also to significantly improve the user experience, making learning more engaging and tailored to individual needs, consistent with previous findings (Ramandanis & Xinogalos, 2023b; Rooein et al., 2022).

## 5 Conclusion

This paper presented the development and application of a chatbot to contribute to active learning in engineering, specifically for process modelling in BPMN. Although other approaches exist in the literature, the authors proposed a low-effort option using a tool available at many universities, thereby potentially reducing implementation costs. The proposed six-step approach enabled the prototyping and evaluation of the chatbot with both master's students and industry professionals. The results demonstrate the potential of the solution, despite limitations in the current version, particularly related to usability and interaction. Among the main positive points, it is worth highlighting the users' perception of the value of this approach as a complement to the learning process.

While the focus was on exploring user perceptions from the experience, the authors believe that various benefits can be gained in future versions of the chatbot. In addition to the improvements identified, there is potential for benefits in reducing teachers' workload, enhancing student engagement, facilitating activities in different languages, and combining bots with other approaches such as gamification. Naturally, new technology options can also be explored, using more advanced language models, voice interactions, and even virtual reality.

The research also presents a series of limitations, mainly related to the current state of the model. For example, only one process was trained, with predominantly predefined questions, and the application was conducted with a limited number of users. To delve deeper into the results, it is necessary to repeat the approach, iterating through all stages based on the learnings from this initial experiment. Future research could explore the development of chatbots in other educational contexts, altering, for example, the role of the chatbot, the topics covered, and the communication traits. It is also suggested to iterate the current model, to incorporate the suggestions raised and characterize processes beyond what the robot was initially trained on.

Therefore, this article contributes to future approaches using low-code chatbots, aiding teachers to plan, develop, and implement their solutions. With a list of positive and negative comments, and suggested improvements, future research can develop prototypes more capable of meeting stakeholder expectations and assisting in active learning in engineering.

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# Digital twins in serial production: a teaching methodology for prototyping in process design

Jair Eduardo Rocha-Gonzalez [1], Jairo R. Coronado-Hernandez[2], Camilo Augusto Garcia-Guevara[3],

[1] Universidad Nacional de Colombia, Facultad de ingeniería, Departamento de ingeniería de sistemas e industrial, ingeniería Industrial, Bogotá D.C., Colombia
[2] Universidad de la Costa, Departamento de productividad e Innovación, Ingeniería Industrial, Barranquilla, Colombia
[3] Universidad Nacional de Colombia, Facultad de ingeniería, Departamento de ingeniería de sistemas e industrial, ingeniería Industrial, Bogotá D.C., Colombia

Email: jerochag@unal.edu.co, jcoronad18@cuc.edu.co, cagarciagu@unal.edu.co

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**Abstract**

This article deals with the design, integration, and development of a sequence of didactic activities for the proposal of improvements in a serial production problem through the construction of an educational experience inspired by an exercise of digital twins, in which it was possible the combination of playful exercises, simulation, construction and contrast of indicators. Thus, this educational experience followed a methodology that included using a physical prototype of a production plant through a playful activity at the beginning and end of the experience. This activity established the initial conditions and a set of proposals for improving manufacturing processes selected from simulated computational experiments. A robust computational simulation tool made implementing the scenarios in the physical prototype possible. This tool allowed us to obtain a digital representation of the playful activity's environment, enabling us to experiment with different scenarios to enhance serial production. The educational experience was a comprehensive integration of various elements. It combined the physical prototype of the recreational activity, the scenario simulation model, and concepts such as the construction of productivity indicators, the use of prioritization and coordination techniques, and the use of contrast techniques in productivity results. All these elements were crucial in determining significant differences between physical prototypes and simulated scenarios. In conclusion, this article provides a detailed description of the experience in engineering education for developing a working session in a workshop modality with which it is possible to facilitate the teaching-learning process of the concepts of serial production, digital twin, and scenario comparison in academic spaces of industrial production, digital simulation, and rapid prototyping in process design.

**Keywords:** Digital Twins; Serial Production; Educational Engineering Methodology, Simulation Model, Playful Activity.

## 1 Introduction

Current trends in engineering education show the use of scale models of factories in academic environments as an element that can benefit the imitation of natural environments through the use of software for the design and management of processes and material flow in production management systems such as ERP, JIT or hybrid among others, which include concepts such as flexibility, volatility, ambiguity, and uncertainty, to encourage the search for solutions to the challenges in the design and management of manufacturing processes, JIT or hybrid among others, which include concepts such as flexibility, volatility, ambiguity, and uncertainty, to encourage the search for solutions to the challenges in the design and management of manufacturing processes by actors involved in research and education processes of these topics (Lutters & Damgrave, 2023).

Thus, it is necessary to implement academic exercises to explain, from the perspective of competitive advantage and value chain strategies, the concepts of mass, serial, and unit production. Mass production, characterized by the manufacture of large quantities of standardized products, is aligned with a cost leadership strategy, allowing companies to reduce costs through economies of scale. Mass production, which involves the creation of batches of similar products, seeks to balance efficiency and flexibility, facilitating customization at certain stages while keeping costs relatively low. Finally, unit production, focused on the creation of unique and highly customized products, is adapted to a differentiation strategy, where the added value and exclusivity of the product justifies a premium price. In each case, the choice of production method impacts the company's cost structure and value proposition, influencing its competitive position in the market. (Porter, 1985; Porter, 2006; Muther & Hales, 1987).

Consequently, the experience reported in this document contains a serial production model in which batches of similar products are produced in a simulated production plant configured with five manufacturing or transformation processes and placed one after the other (Merengo, Nava, & Pozetti, 1999; Becker & Scholl, 2006), to elaborate a batch of defined or calculated size in advance to the realization of the ludic activity, this process is described in Figure 2, aspect that is sought to be simulated in the same way described to start the changes in the simulation model that provide improvements. (Law & Kelton, 2007)

In this perspective, the development of learning with factory models in academic environments establishes a challenge in the inclusion of changes in a manufacturing process that can be replicated to perform the analysis, monitoring, and evaluation with the use of an appropriate software solution and in coherence with the production management system under study (Lutters & Damgrave, 2023) as in reality, an aspect that can have many different approaches from the educational vision among which the use of learning factories is one of the most expanding in Europe (Abele, y otros, 2015).

Therefore, the definition of a learning factory is established as a learning environment with authentic processes, with multiple process stations that include technical and organizational aspects in a changing environment that resembles a real value chain, with a physical product produced under a didactic concept comprising formal, informal and non-formal learning, in which learners perform learning actions in situ (Abele, y otros, 2015; Abele, 2016).

From this point of view, the learning factory is conceived as a facility for realizing products and processes for academic education, which includes student active participation, an agile environment, and an approach to reality that resembles an authentic simulation (Abele, Tenberg, Wennemer, & Cachay, 2010; Abele, y otros, 2017), which can follow different methodologies for its development (Tisch, y otros, 2013), which with pointing out common aspects that relate in the various learning factory experiences to concepts such as purpose, process, settings, product, didactics, and operating model, as described in the literature about topic Learning Factories (Abele, y otros, 2017; Abele, y otros, 2015; Initiative on European Learning Factories, 2013; Lu, Shpitalni, & Gadh, 1999; Thomar, 2015; Sivard & Lundholm, 2013; Kemény, Beregi, Erdős, & Nacsa, 2013).

Now, it is necessary to recognize that learning factories represent from reality, manufacturing processes that, in turn, have software developed for their planning, monitoring, and control that act with rules adapted to the typical behavior of the system in which it is framed through the definition of the production management system, interaction considered as a robust environment in operations but also inflexible and rigid in the face of changes in the number and diversity of products, in the manufacturing process, or the availability of resources, aspects frequently questionable in the processes of learning and research in manufacturing, limiting the introduction of new technologies, work methods, and personnel training in reality (Lutters & Damgrave, 2023).

Given this industrial reality and its representation with models of learning factories, it is necessary to consider the conception and methodology accepted for the execution of these experiences; it is essential to implement techniques that promote the meeting of learning with the conception of processes and product manufacturing in a didactic environment, aspect possible to perform through the use of digital twins, which is considered as one of the basic techniques for the integration of education with research in digital factories (Lutters & Damgrave, 2023).

Thus, in some studies, it has been possible to include in the development of digital twins in learning factories elements such as the internet of things, planning processes, diagnosis, monitoring, and quality control, as well as the use of a digital for the projection of future and potential activities that represent an improvement or evolution of the exercise for educational and research purposes (Lutters & Damgrave, 2023), aspects that coincide with the methods and objectives of a learning factory.

It is also necessary to highlight that this article coincides with studies (Lutters, 2018) in which the use of digital twins has been tested for the achievement of objectives around the exploration of future scenarios discarding risk, analyzing different perspectives regardless of the information system of one or another production management system (Lutters & Damgrave, 2023) and fostering the integration of students' problem-solving skills with a real and a simulated scenario (Slot & Lutters, 2021), with their corresponding interrelationship regardless of their level and discipline of training.

Thus, the real scenario proposed in this article includes some elements of complexity of reality that are related to uncertainty and adaptability of the processes, which, when represented in the digital model, will allow the analysis and understanding of the effects of decision-making in the introduction of new technologies, changes in the process sequence or evaluation of the addition or subtraction of available resources, (Lutters & Damgrave, 2023) aspect that agrees with the results of other studies that perform processes of this type, and that lead to foresee potential future situations in reality through the digital model (Lutters, 2018).

Finally, this article also incorporates the concept of a digital system in which three components are defined (Lutters & Damgrave, 2023; Slot & Lutters, 2022): the digital twin, the digital master, and the digital prototype, in which the digital twin, includes the current state of the system considering the data and information of the process, the models and methods in use, as well as the tools and techniques used in the monitoring and control aspect which is the focus of this paper, in addition to the digital master which represents the future state of the system, and the digital prototype which allows the exploration and analysis of possible changes in through simulation enabling to establish a measure of differences between the first two components (Lutters & Damgrave, 2023; Slot & Lutters, 2022).

## 2 Methodology

This article focuses on the description of a learning factory in which a classroom exercise is connected with simulation technologies through the use of an elementary-level digital twin for the generation of competencies in engineering students in Colombia by the requirements for the reduction of manual work and the increase of cognitive, social and emotional and technological competencies foreseen for the year 2030 (Dahl, Tvenge, Assuad, & Martinsen, 2023; Ellingrud, Gupta, & Salguero, 2020).

In which an analysis is made of the skills required in the United States and Western Europe in 2016 and its projection in the change of the proportion of combination for the year 2030 in this same geographical region, which can be summarized as a decrease in manual and physical skills from 48% to 35%, The same as basic cognitive competencies from 12% to 10%, while an increase in higher competencies from 17% to 21%, socioemotional competencies from 12% to 16% and technological competencies from 12% to 19% is required, this last aspect with a strong emphasis on the prospective in industrial engineering education, which is the focus of the development of this article. (Dahl, Tvenge, Assuad, & Martinsen, 2023; Ellingrud, Gupta, & Salguero, 2020).

Based on this competency development, the digital twin design case study followed a methodology that combined two methodologies for the development of learning factories. Six concepts related to learning and the development of the pedagogical device were formulated: purpose, process, settings, product, didactics, and operating model. (Abele, y otros, 2017; Dahl, Tvenge, Assuad, & Martinsen, 2023)

In addition, the case study included the use of physical prototyping of a production plant for mass production with a push management strategy. Participants must produce a set of fifty similar products with differences in two attributes of the material used. This physical prototype was built in a playful environment where each work team was divided into two subgroups, one in charge of production and the other recording information about the manufacturing process. After the data collection, these are taken to a computer room where the statistical data analysis is performed. A set of indicators is constructed, with which it is possible to build a multidisciplinary simulation model of the game, in which many experiments are performed to determine possible futures and present simulated measures that can be compared with the prototype of the initial game.

Once a more favorable scenario is identified through the comparison of indicators from various simulations, the entire multidisciplinary team comes together to assemble and install this scenario. This collective effort is followed by a run of fifty products, each with the same characteristics, for a new data collection. This data is then used to generate a third set of indicators, which are compared with the initial game and the simulation results, as part of our ongoing development process.

## 2.1 Purpose

The purpose of the digital twin used in this learning factory is to provide a practical application for the development of competencies in the design of processes with elements of innovation and under the concept of minimum viable product (MVP). This involves the construction of a process with minimum functions and the lowest possible cost that allows adjustments to achieve better performance in mass production with a spatial configuration in line. With this premise, the learning outcome of the proposed learning factory was that the students were able to make decisions in the design of the manufacturing process for the improvement of the management indicators of a serial production system with spatial configuration in line; for this, the achievement of some achievement indicators are considered.:

- Calculate performance measures for productivity (quantity of products, cycle time per unit, operation time per unit, and total manufacturing time of the production batch) and quality (number of defective and non-defective products).
- Set up a model of production system management indicators to compare production systems suitable for evaluating each operation and the production system as a single element.
- Build a replicated computer simulation model of the initial production performed in a playful environment, which can be further modified to propose desired future scenarios.
- Replicate the calculation of performance measures in each of the digital factory's phases: initial game, simulated models, and game with improvements. This will establish significant differences between the different phases, which will be used to evaluate the effect of the actions taken.
- Modify the process design in the simulation and in the final prototype to obtain significant differences in the performance measures and the set of indicators of each stage of the development of the learning factory.

Therefore, this new learning scenario contrasts with traditional teaching methods that limit the development of competencies for challenges in current and future manufacturing scenarios (Cachay, Wennemer, Abele, & Tenberg, 2012).

## 2.2 Process

The process in the learning factory, according to the literature on the subject, includes multiple process stages that include various technical and administrative aspects; in this way, the learning factory proposal is a playful bet taken from the compendium of games of an educational institution in Colombia (GEIO research group -

Universidad Tecnologica de Pereira, 2009), in which an adaptation of simulation exercises performed in other contexts and taken to the learning environment present in the country is made.

This playful activity includes five process stations, which are performed manually by five participants who have the role of operators; it is noteworthy that each of these operations requires different fine motor skills, which makes the first problem to be overcome by the work teams is the selection of the right person to perform each of these operations according to their physical development conditions and an adequate level of concentration because they are repetitive operations in the placement of Lego® chips inside a covered container.

A second aspect that represents another challenge is the coordination of the line under the push configuration, which will generate inventories in process between the different process stations, in addition to having different manufacturing rhythms in the production batch that are generated from a Monte Carlo simulation which randomly generates the colors (four different colors) equiprobable of two Lego® chips that will contain a container with a lid for the fifty products to be made. Considering the above technical and organizational aspects of the recreational activity, the manufacturing process of the products follows the following manufacturing process in Figure 1.

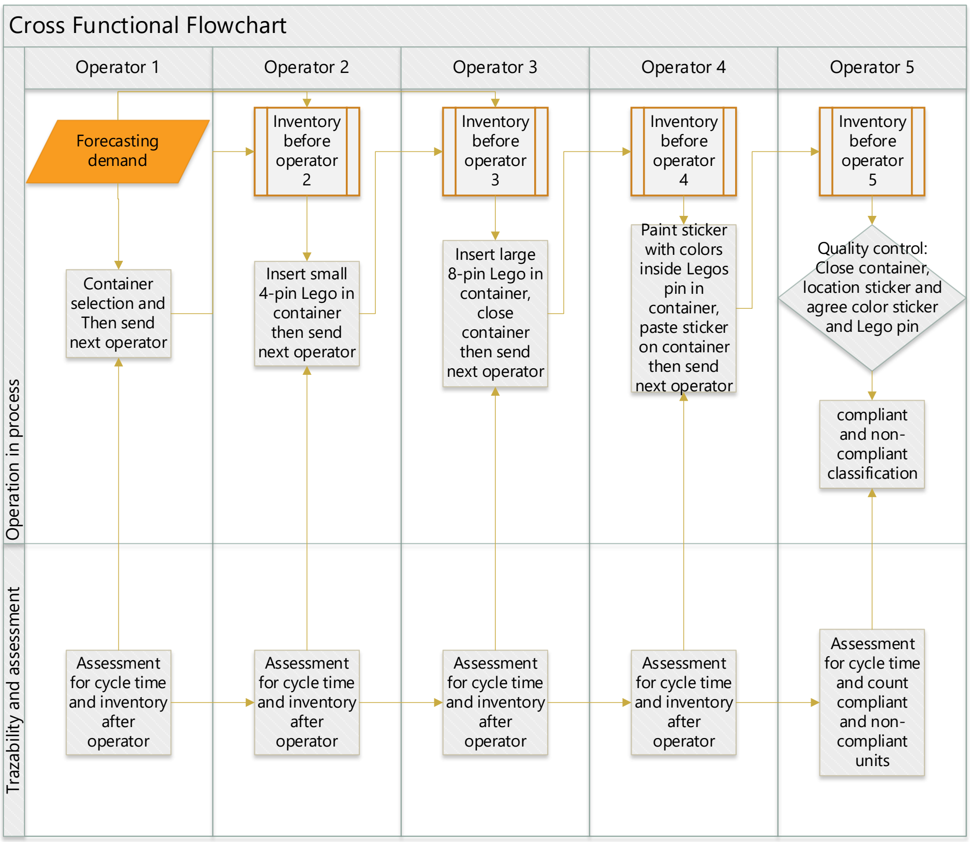


Figure 1. Learning factory process for the initial prototype of the mass production system with in-line spatial configuration.

After this initial setup, the initial conditions of the manufacturing process in the learning factory are established. The process performance measures are determined in two dimensions: productivity (quantity of products, cycle time per unit, operation time per unit, and total manufacturing time of the production batch) and quality (number of defective and non-defective products); it is necessary to perform a statistical analysis to determine the input parameters for the simulation model which followed the steps detailed in Figure 3 for the process times, while for the quality dimension, the fraction of non-conforming products is established through the calculation of probabilities with a binomial probability distribution function.

After the estimation of the probability distributions with their respective parameters that represent the operation times in each process station, the simulation model is built in suitable software, for which SIMIO® has been selected in its version available for the date on which the execution of the learning factory has been carried out. This software selection has to do with its ease of use and its environment inspired by the flow of materials, which does not require linking different graphic elements to the simulation.

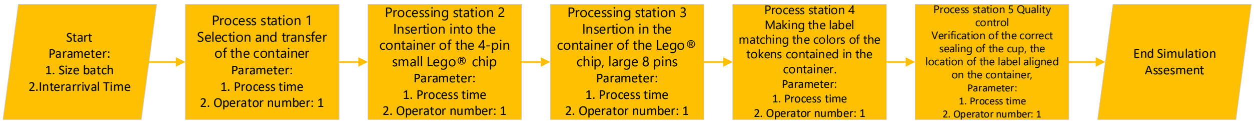


Figure 2. Simulation model for Simio® of the mass production system with in-line spatial configuration.

The formulation of the simulation model, which will be the digital twin, follows the process diagram shown in Figure 3 in the operation phase, incorporating the parameters and probability distributions in a model with five process stations, five buffers that represent the intermediate inventory between the process stations and the finished product warehouse, with which the group of students performs a validation process against the real twin, obtaining a representative result to finally start the experimentation process according to the possible changes described in the adjustments section of this document.

It is noteworthy that the digital twins are built by teams of students from different branches of engineering, who, through the different occupational profiles, contribute possible changes that can be implemented through a process that involves mediation, teamwork, and active participation; this process is done through techniques such as brainstorming and weighting exercises of alternatives and in some cases using online software for text analysis.

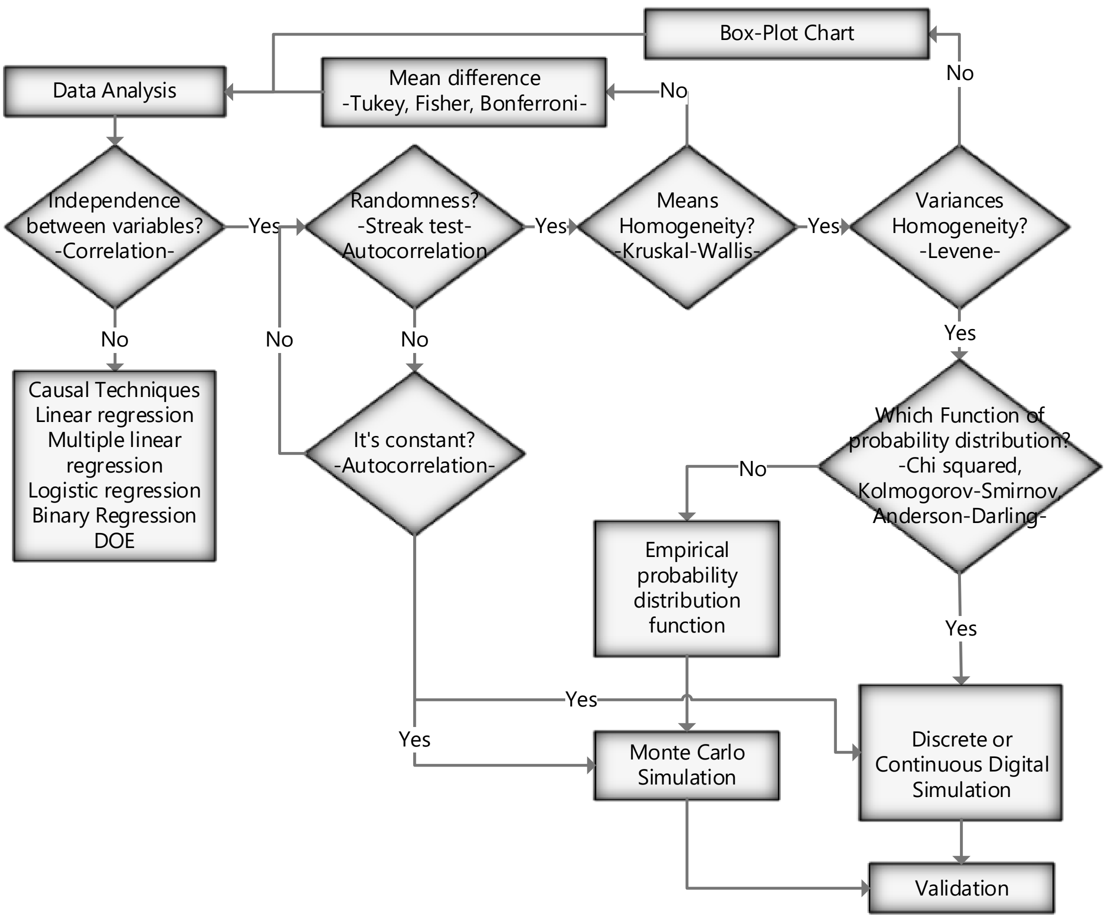


Figure 3. Data analysis process for information from the initial prototype of the learning factory.

Now, simultaneously, once the parameters of the probability distributions for the different operation times, the number of products produced, and the number of conforming and nonconforming products are, it is possible to build a model of process operation indicators in which a form of relationship of the performance measures is used in which it is possible to include a part or all of them, with which it is possible to characterize the behavior of each of the stages of the learning factory process: initial actual prototype or real twin, digital prototype in simulation or digital twin and final real prototype or digital twin and the real and digital master which is the final prototype, an example of the formulation of indicators is possible to see it in table 1.

These indicators evaluate production rates, batch sizes, and average times per manufactured unit, with which it is usually possible to evaluate the performance of a real production system generated from the learning factory, besides being a fundamental part of the formulation of the digital scenarios that are simulated, helping the evaluation of each one of them, discarding those with worse performance according to the directives that govern the game in terms of maximization of production volume, minimization of cycle times and impact of the change of outputs in the process design, as indicated in various models of evaluation of systems with a material flow such as factory physics, theory of constraints, among others.

Table 1. Model of indicators for the evaluation of the different phases of the learning factory and their comparison among themselves.

| | **Cycle time per batch (min)** | **Number of units completed (U1)** | **Number of Non-Compliant Units (U2)** |
|---|---|---|---|
| **Cycle time per batch (min)** | 1 | $Cycle\ time\ unit = \frac{Min}{U1}$ | $Arrival\ non\ compliant = \frac{Min}{U2}$ |
| **Number of units completed (U1)** | $Rate\ production = \frac{U1}{min}$ | 1 | $Size\ lot\ fraction\ add = \frac{U1}{U2}$ |
| **Number of Non-Compliant Units (U2)** | $Rate\ production$ $non\ compliant = \frac{U2}{min}$ | $Non\ compliant\ fraction = \frac{U2}{U1}$ | 1 |

Finally, the process concludes with the selection of the digital twin to be implemented in the final prototype of the learning factory, which is made from the multidisciplinary analysis of engineering students with different profiles, which is performed by direct analysis of the differences of the performance measures and operation indicators by the last achievement indicator proposed by a set of teachers, to be subsequently implemented in the real prototype in which it is returned to real twin to test the simulated hypotheses in reality with its corresponding measurement and comparison with the initial phase and the simulation phase.

## 2.3 Settings

In this area, the proposed learning factory takes into account the concept of the literature on the subject, which consists of a changing environment that resembles a real value chain, which is represented through the possible changes that can be made in the initial configuration of the recreational activity in the scenarios to be simulated and the final prototype with changes, which can be defined as shown in Table 2.

Table 2. Possible changes in the manufacturing process proposed in the learning factory.

| Organizational level of changes | Possible changes |
|---|---|
| **Strategic** | • Change in the production management system to JIT, CONWIP or other.<br>• Addition of strategic objectives such as profit maximization, revenue, production volume, capacity utilization or cost minimization, and productive leisure.<br>• Addition of new operations before or after the above processes. |
| **Tactical** | • Changes in the sequence of operations to manufacture the product.<br>• Changes in the probability of occurrence of Lego® colors in the forecasted demand.<br>• Use of downstream material flow coordination formats in the simulated value chain. |
| **Operational** | • Changes in workstation design in terms of orientation, location, and type of tools in each operation.<br>• Changes in the ergonomics of the workstation in each operation in the initial environment start in a standing position.<br>• Addition or reduction of resources such as operators at each process station.<br>• Combining or separating operations by grouping them in new or eliminated process stations.<br>• Use of Poka-Yoke elements to improve the sequence or fundamental elements of the method in each operation. |

The above adjustments have been compiled from numerous executions with various groups of engineering students in regular courses ranging from the beginning of the program to the last semester in industrial engineering and the field of international professorship for students of systems engineering, mechatronics, mechanical, civil, electrical and electronics, as well as students of the health area in nutrition and nursing.

It is also useful to say that the adjustments in reference are not the only ones possible since the improvement of production processes is a continuous task that also involves the formulation of new alternatives and methods; this can be an opportunity for improvement in the learning factory by not having limitations on the number and type of changes.

## 2.4 Product

The proposed learning factory makes a simple product in five different operations. This product consists of a container that contains two Legos® inside. The first one is small, has four pins, and can have one of four colors selected for the exercise according to the availability of materials, while the other one is large, has eight pins, and has one of four colors available.

As the manufacturing process nears completion, the product is sealed with a hermetic lid, ensuring the integrity of the container. This sealed container houses two Legos® of different sizes and colors, often corresponding to the colors available. The product is then adorned with a sticker, meticulously painted with office elements in the same colors as the Legos® inside. This sticker is carefully aligned with a characteristic of the container, adding a final touch of precision.

The product quality characteristics to be verified in each unit are the hermetic seal of the container, the content of two Legos® of different sizes inside the container, the correct alignment of the sticker, and the correspondence of the colors of the sticker and the Legos® inside the container.

## 2.5 Didactic

Didactics are critical in implementing an active learning model, especially when teaching complex concepts such as push production systems. By incorporating a playful activity into the learning factory, such as a simulation game with a digital twin model, students can interact with realistic scenarios to experience the concepts in real-time. This hands-on experience facilitates understanding the principles underlying the push production system and its relationship with other components of the production process.

Students can assume specific roles within the production system in this activity, such as operators with different manual skills. Through simulation, students decide how to organize the production flow, manage available resources, and optimize the process to maximize efficiency and minimize waste. This dynamic fosters collaboration and teamwork, as students must coordinate their actions to achieve the objectives of the production system.

Using a digital twin model in the play activity allows students to see the results of their decisions in real time and adjust their strategy accordingly. This immediate feedback helps them better understand the consequences of their actions and develop critical thinking and problem-solving skills. In addition, the digital twin model provides a safe environment to experiment and learn from mistakes, which fosters innovation and adaptability in the learning process.

## 2.6 Operation model

The operation model allows to establish the desired continuous operation of the learning factory in this way, the proposed ludic activity has a plant distribution as shown in Figure 4 in which a sequence of the initial processes for the development of the digital twin is established, which has the opportunity of a great variety of possible changes that could not be listed in its entirety due to the complexity of the operation in the proposed serial process.

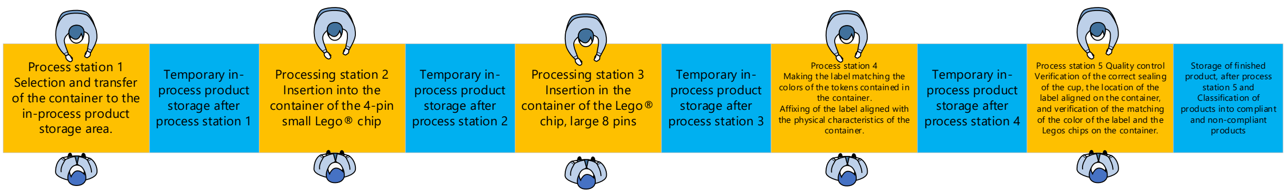

Figure 4. Facility layout with the operating model of the play activity in the proposed learning factory.

The first analysis that allows the operation model for the learning factory is the evaluation of changes through an analysis of operations and methods with traditional methods described in the literature, followed by an analysis of workstations, and ergonomics, among other aspects, to subsequently perform analysis of required and available capacity by type of resource, task scheduling or finally perform analysis of production management systems and incorporation of techniques specific to each of these.

These analyses incorporate numerous concepts and technical tools that when implemented in the digital model can obtain diverse and valuable results that allow to have different experiences in each team of participants when shared indicate paths with solutions sometimes not treated traditionally but that work in the reality of the educational model.

Figure 5 shows some images of the execution of this initial operation model by working groups of the engineering faculty of the National University of Colombia in Bogotá, D.C., Colombia.

(a) (b) (c)

Figure 5. (a) Play activity in the product assembly process according to the operation model described. (b) Experimentation exercise of different scenarios with the simulation software in use. (c) Socialization of results of the designed learning factory exercise

# 3 Results

Finally, the results of this article consist of the presentation of a teaching methodology for rapid prototyping in process design, consisting of six steps, which were achieved from a methodology used for the construction of meaningful experiences for learning factories. (Abele, y otros, 2017; Dahl, Tvenge, Assuad, & Martinsen, 2023), in which the concepts of purpose, process, settings, product, didactics, and operating model described in the article are included.

Thus, the methodology achieved is integrated by a playful activity at the beginning and end of the activity, followed by two moments of measurement of variables in reality and the simulation model, two moments of evaluation of alternatives under process design precepts in the simulation model and the final playful activity, and a moment of contrast of measurements to determine the degree of change between the initial and final condition of the production plant as defined in Figure 6.

Finally, by working with different groups of industrial, mechatronics, mechanical, chemical, and systems engineering students, it was possible to observe changes in the configuration of the production system in three fundamental aspects:

- Changes in installed capacity in each of the process stations, by adding, deleting, or repositioning the number of operators assigned to each process station to perform a process line balancing process and decrease process inventories without affecting operating times in each process station.
- Changes in the materials, tools, transformation methods, and arrangement of the workstations for each station which it was achieved the reduction of operation times in each one of the transformations reducing the cycle time of elaboration of a production lot with a minor impact in the inventories of material in process.
- Changes in the manufacturing sequence by making a new process that has achieved a decrease in the operation times in each process station and the inventories of material in process, being this one of the most radical changes that have worked in the improvement of the process design in the prototyping stage.

It is noteworthy that many groups have achieved other types of changes that have not had significant changes between the initial condition of the learning plant and the one obtained at the end of the exercise, these changes have also had feedback as possible changes that have not affected the result of the prototype of the learning plant, an aspect that has served as an element of control and test of the improvement hypothesis.

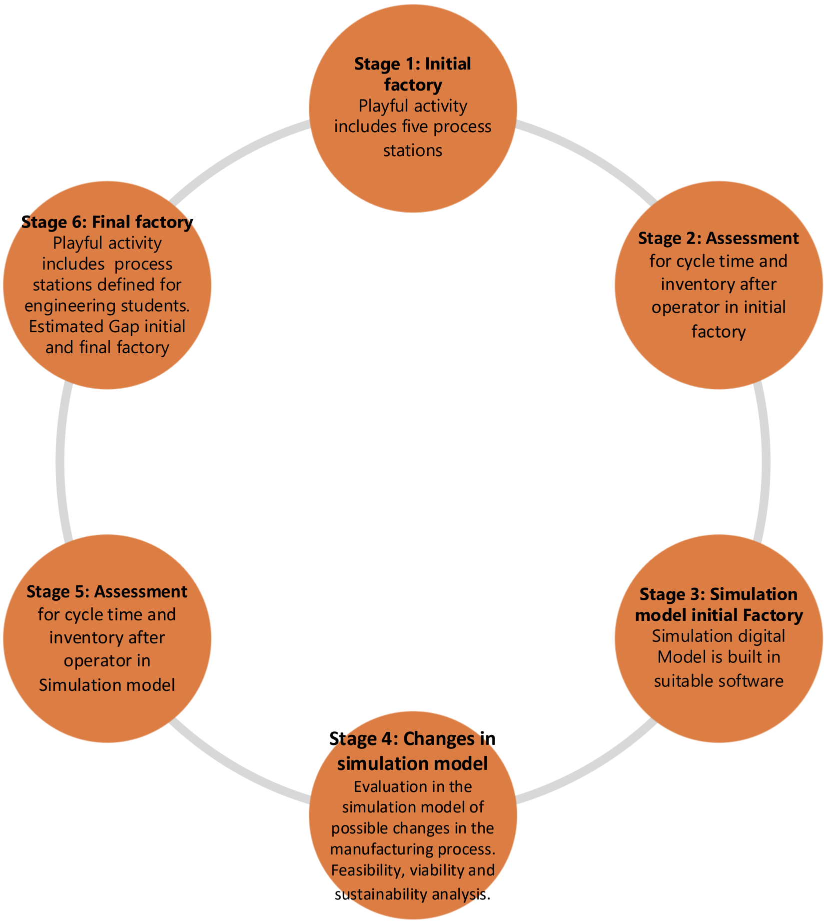


Figure 6. Teaching methodology for prototyping in process design.

# 4 Discussion

The success of the playful activity with digital twins highlights the importance of integrating advanced technologies into education, especially in fields related to production and industry. By combining active learning approaches with case study methodologies, students can relate theory to practice more meaningfully and retentively.

The concept-based approach formulated by Abele et al. (2017) and Dahl, Tvenge, Assuad, and Martinsen (2023) provided a sound structure for designing the pedagogical activity, ensuring that all key aspects of learning and development are addressed. This structure also facilitates evaluating the effectiveness of the activity and provides a framework for future improvements. However, it is crucial to recognize that the success of this activity depends on several factors, such as the quality of the simulation, the instructors' preparedness, and the student's willingness to participate actively in the learning process. In addition, the implementation of digital twin technologies may require a significant investment in resources and training, which may be a challenge for some educational institutions, which may have an alternative to this activity using low-cost materials and a free academic simulator, which may be accessible and beneficial for institutions with limited resources without reaching a high level of automation.

# 5 Conclusions

The digital twin model based on a playful activity has proven to be an effective tool for teaching thrust production systems. Students were able to experience a simulated environment in which the six key concepts relating to learning and development of the pedagogical device were applied: purpose, process, settings, product, didactics, and operating model. This allowed students to develop a deeper understanding of the principles of thrust production and how they apply them in a real-world context. The use of a digital twin provided students with immediate feedback on their decisions, allowing them to adjust their strategies in real time and improve their performance on the production system. In addition, the model allowed for a collaborative, hands-on learning experience, fostering teamwork and the development of problem-solving and critical-thinking skills. In summary, the playful activity using digital twins for teaching push production systems has not only been an enriching educational experience for students but has also proven to be an effective methodology for facilitating the understanding and application of complex production concepts.

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# Interdisciplinary Integration in Engineering Education: Integration of Predictive Statistical Model Generation for Chronic Disease Prediction through Fingerprint Dermatoglyphics

Román Leonardo Rodriguez-Florian[1], Laura Elizabeth Castro-Jiménez [2], Jair Eduardo Rocha-Gonzalez[3]

[1] Universitaria Agustiniana, Facultad de ingeniería, Ingeniería Industrial, Bogotá D.C., Colombia
[2] Universidad Pedagógica Nacional, Facultad de educación física, Licenciatura en deporte, Bogotá D.C., Colombia
[3] Universidad Nacional de Colombia, Facultad de ingeniería, Ingeniería Industrial, Bogotá D.C., Colombia

Email: roman.rodriguez@uniagustiniana.edu.co, lecastroj@upn.edu.co, jerochag@unal.edu.co

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**Abstract**

This article addresses experiences in engineering education, which focuses on integrating knowledge between the health sector and industrial engineering to develop mathematical models for predicting chronic diseases using fingerprint dermatoglyphics as a key source of information. A process has been carried out in which fingerprint dermatoglyphic has been recognized as a valuable marker for the prediction of chronic diseases, in which the combination of medical knowledge and industrial engineering skills has had an outstanding impact on the construction of a methodology for the understanding of dermatoglyphic patterns associated with the prediction of predisposition to various chronic, according to the existing literature in the health sector. Thus, the methodology established in the current study presents a detailed description of the data acquisition methods, processing techniques, and statistical analysis with which it was possible to collect and extract significant information from the dermatoglyphic impressions, it is computer processing to convert them into useful databases to conclude with a phase of statistical analysis with which it was possible to build a predictive model with a high level of accuracy and robustness in the prediction of specific chronic diseases. Finally, a descriptive analysis is made of the process of integration of knowledge from the areas of health and engineering, during the methodology being developed in the study in progress, in the aspects of construction of a common language, solution to challenges from a shared vision for the achievement of the objective and joint interpretation of results to obtain multidisciplinary conclusions about the relationship between the phenomenon under observation and the predictive model built. In summary, this article provides a vision of an experience that required the collaboration of two different but complementary disciplines to propose low-cost and non-intrusive techniques for the early detection of genetic predisposition to certain chronic diseases.

**Keywords**: Interdisciplinary Integration Concepts; Statistics Model Prediction; Fingerprint Dermatoglyphics; Educational Engineering Methodology.

## 1 Introduction

Currently, the need for interdisciplinary work has become evident to address the problems that arise in different sectors such as the economy, the use of technologies, and health and disease, to name just a few. In this sense, biotechnology has had multiple applications in different scenarios such as tissue engineering, cellular engineering, biotechnological drugs, vaccines, and identification of genetic determinants associated with various diseases (Reza, 2011).

Chronic non-communicable diseases (NCDs) affect humanity in large proportion representing a significant percentage of mortality in the population, according to the World Health Organization (WHO) 41 million people equivalent to 71% lose their lives each year due to disease (Colantonio, y otros, 2021; Seclen-Santiesteban, 2021), in the region of the Americas deaths are 5.5 million annually. The highest rate of deaths is constituted by cardiovascular pathologies representing 17.9 million people each year (PAHO/WHO, 2018). For this reason, it is essential to address strategies not only for prevention but also for early detection of these pathologies. NCDs are divided into four major disease subgroups: cardiovascular, where hypertension and acute myocardial infarction lead morbidity rates, cancer, respiratory diseases and finally, diabetes. Together, mortality from all these diseases accounts for 75% (32 million) of the entire world population, affecting middle and low-income countries to a greater extent (Estrada-Brizuela, y otros, 2021).

The economic burden represented by the group of the four most relevant chronic noncommunicable diseases (cardiovascular, cancer, chronic respiratory, and diabetes) has a severe impact on the economic systems of each country; according to the World Health Organization, it is projected that during the period between 2011 and 2025, the cumulative loss of production of low and middle-income countries will be 7.28 trillion dollars per year (World Health Organization (WHO), 2023). A report issued by the World Economic Forum defined that this group of diseases is an important risk factor for developing high unemployment and poverty rates in a society (Pan American Health Organization (PAHO); World Health Organization (WHO), 2018).

Motivated by the current challenges, it is becoming usual the contribution from engineering to other areas of knowledge, and as mentioned one of the areas of work of biotechnology, is the digitization and digital transformation for different purposes such as the recognition of genes or genetic markers to achieve predictive models and determine risk factors for presenting a chronic noncommunicable disease (NCD) (Ibañez, Ribera, & Rodriguez-Lluesma, 2023). In this sense, dermatoglyphics, a science in charge of studying the design of papillary ridges that can present pertinent and precise data on physical and genetic characteristics that directly influence the health of the individual, can be a low-cost technique that generates information to identify risk factors and predict the appearance of pathologies that are preventable and that being diagnosed early, allow mitigating the impact on the sequels, generating well-being in the early stages of the vital cycle. It should be noted that fingerprints are formed during gestation and become a reliable indicator that remains throughout life, thus being an immutable element; papillary ridges are found on the palms of the hands which are correlated with the early manifestation of NCDs (Ghislaine-Morizon & Aspillaga, 1977).In this sense, dermatoglyphics, a science in charge of studying the design of papillary ridges that can present pertinent and precise data on physical and genetic characteristics that directly influence the health of the individual, can be a low-cost technique that generates information to identify risk factors and predict the appearance of pathologies that are preventable and that being diagnosed early, allow mitigating the impact on the sequels, generating well-being in the early stages of the vital cycle. It should be noted that fingerprints are formed during gestation and become a reliable indicator that remains throughout life, thus being an immutable element; papillary ridges are found on the palms of the hands which are correlated with the early manifestation of NCDs (Ghislaine-Morizon & Aspillaga, 1977). The use of dermatoglyphic fingerprinting as a predictive method for chronic noncommunicable diseases would provide beneficial information that would translate into a decrease in the incidence of these types of pathologies that affect human well-being, and would also alleviate the costs that they entail for the health system of each country (Girod-Frais & Bécue, 2021), Finally, it could improve primary prevention actions and thus have a positive impact on the welfare of the population in low and middle-income countries, reducing mortality rates and in general terms providing a solution to the problems experienced in recent decades at the global level (Castro-Jimenez, Rodriguez-Florian, & Rocha-Gonzalez, 2023). The use of dermatoglyphic fingerprinting as a predictive method for chronic noncommunicable diseases would provide beneficial information that would translate into a decrease in the incidence of these types of pathologies that affect human well-being, and would also alleviate the costs that they entail for the health system of each country (Girod-Frais & Bécue, 2021), Finally, it could improve primary prevention actions and thus have a positive impact on the welfare of the population in low and middle-income countries, reducing mortality rates and in general terms providing a solution to the problems experienced in recent decades at the global level (Castro-Jimenez, Rodriguez-Florian, & Rocha- Gonzalez, 2023).

Engineering contributes by proposing a model that can be applied in the field of health conditions of the population in general, which would allow early recognition of people at risk of NCDs. as has been described in different studies with methods that use neural networks as an element of categorization (Darji, Darji, Nisar, & Joshi, 2021; Alsharman, Saaidah, Almomani, Jawarneh, & Al-Qaisi, 2022), statistical methods for variations in populations (Etta, Petu, Etukudosh, & Uyannah, 2014), Deep learning for automated fingerprint identification systems (Ametefe, Sarnin, Ali, & Muhammad, 2023).

# 2 Methodology

## 2.1 Type of research

This research is framed within a quantitative approach, given that numerical data will be collected to understand cause and effect correlations that will be the object of analysis for the construction of the prediction model. The study will adopt an analytical-correlational scope and an experimental intervention strategy will be implemented. In terms of its temporal design, it is classified as cross-sectional, given that data will be collected at a single point in time with no subsequent follow-up.

## 2.2 Sources of information

In this research, primary sources of information are used, which were collected directly through data collection sessions in Higher Education Institutions, with students belonging to the engineering faculty of different semesters.

## 2.3 Data collection instruments

For the data collection of this research, different instruments were used, which are described below:

- Survey: two surveys were designed to collect data on healthy lifestyle and physical fitness assessment. The model of these surveys can be found in the appendix section (appendix 1, appendix 2).
- Elite Hem digital blood pressure monitor: It is a medical device used to measure diastolic and systolic blood pressure and pulses per minute.
- SECA portable measuring rod: An instrument used to measure a person's height.
- Tanitna Body Scale: Device used to measure a person's weight and other variables.
- Fingerprint reader WM110CA-E00: A technological device used to scan images of the ridges that make up the fingerprint.
- Statgraphics: Program used for statistical analysis of data.

## 2.4 Population and sample size

This section will present the results obtained from the development of the research and the generation of the mathematical model for the prediction of predisposition to suffer NCDs in students from various higher education institutions in the city of Bogota, through fingerprint dermatoglyphics.

The target population of this research is young university students, and the sample is composed of students from various institutions of higher education in the city of Bogota, who are between 18 and 26 years old, reaching a population of 400 individuals which has a sample size of 90 students.

During the data collection sessions, a sample of 90 students was obtained, the results of which indicated that, in general, the average height was 169.79 cm (SD ± 8.12 cm), with a maximum of 189 cm and a minimum of 142.5 cm. In the weight variable, an average of 65.67 kg (SD ± 9.79 kg) was obtained, where the maximum weight was 96.3 kg, and the minimum was 50.1 kg. In the BMI variable, the average was 22.75 $Kg/Cm^2$ (SD ±

2.73 Kg/Cm[2]), where the maximum was 34.20 Kg/Cm[2] and the minimum was 17.45 Kg/Cm[2]. The results of these variables by gender are shown in Tables 1 and 2.

Table 1. Height, weight, and BMI data for male

| | Male | | | | |
|---|---|---|---|---|---|
| | **n** | **Mean** | **Deviation** | **Maximum** | **Minimum** |
| **Height** | 73,00 | 172,44 | 6,062296 | 189,00 | 160,50 |
| **Weight** | | 67,64 | 9,418810 | 96,30 | 50,30 |
| **BMI** | | 22,73 | 2,696434 | 34,20 | 17,45 |
| **%** | 81,11 | | | | |

Table 2. Height, weight, and BMI data for female

| | Female | | | | |
|---|---|---|---|---|---|
| | **n** | **Mean** | **Deviation** | **Maximum** | **Minimum** |
| **Height** | 17,00 | 158,74 | 5,635380 | 167,90 | 142,50 |
| **Weight** | | 57,27 | 6,476180 | 74,10 | 50,10 |
| **BMI** | | 22,80 | 2,965096 | 29,05 | 18,58 |
| **%** | 18,89 | | | | |

On the other hand, in the dermatoglyphic data variables, it is evident that two figures predominate in the right hand, the first is the radial clasp with 225 figures equivalent to 50% of the total figures of the right hand, having a greater presence in finger 3 and 5 with 64 figures each. The second predominant figure is whorl 193 figures equivalent to 42.89% of the total figures of the right hand, having a greater presence in finger 1 with 58 figures.

Table 3. Dermatoglyphic data right-hand

| | Dermatoglyphic data right-hand | | | |
|---|---|---|---|---|
| **Fingers** | **Ulnar Loop** | **Radial Loop** | **Whorl** | **Arch** |
| **MDT1** | 0 | 32 | 58 | 0 |
| **MDT2** | 14 | 33 | 34 | 9 |
| **MDT3** | 1 | 64 | 20 | 5 |
| **MDT4** | 0 | 32 | 55 | 3 |
| **MDT5** | 0 | 64 | 26 | 0 |
| **Total** | 15 | 225 | 193 | 17 |
| **%** | 3,33 | 50,00 | 42,89 | 3,78 |

Concerning the left hand, the predominant figures are two, the first is the radial clasp with 233 figures equivalent to 51.77% of the total figures of the left hand, with a greater presence in finger 5 with 66 figures. The second predominant figure is the whorl with 178 figures equivalent to 39.55% of the total figures of the left hand, with a greater presence in fingers 1 and 4, both with 49 figures.

Table 4. Dermatoglyphic data left hand.

| | Dermatoglyphic data left-hand | | | |
|---|---|---|---|---|
| **Fingers** | **Ulnar Loop** | **Radial Loop** | **Whorl** | **Arch** |
| **MET1** | 0 | 35 | 49 | 6 |
| **MET2** | 15 | 31 | 36 | 8 |
| **MET3** | 2 | 61 | 21 | 6 |
| **MET4** | 0 | 40 | 49 | 1 |
| **MET5** | 0 | 66 | 23 | 1 |
| **Total** | 17 | 233 | 178 | 22 |
| **%** | **3,78** | **51,78** | **39,56** | **4,89** |

**Variables selection**

Twenty-two variables were selected from the sample of 30 students that met the description of the target population. After having the data in tables, the relevant variables were selected for the construction of the mathematical model, which is described below.

**Independent variables**

MDSQL1: Right-hand finger 1 crest.
MDSQL2: Right-hand finger 2 crests
MDSQL3: Right-hand finger 3 crests
MDSQL4: Right-hand finger 4 crests
MDSQL5: Right-hand finger 5 crests
MESQL1: Left-hand finger 1 crest
MESQL2: Left-hand finger 2 crests
MESQL3: Left-hand finger 3 crests
MESQL4: Left-hand finger 4 crests
MESQL5: Left-hand finger 5 crests

MDT1: Figure type finger 1 right hand
MDT2: Figure type finger 2 right hand
MDT3: Figure type finger 3 right hand
MDT4: Figure type finger 4 right hand
MDT5: Figure type finger 5 right hand
MET1: Type of figure finger 1 left hand
MET2: Type of figure finger 2 left hand
MET3: Type of figure finger 3 left hand
MET4: Type of figure finger 4 left hand
MET5: Type of figure finger 5 left hand

**Dependent variables**

Depending on the type of chronic non-communicable disease on which the analysis is focused, several dependent variables can be taken, such as:

DBP: Diastolic Blood Pressure of the Individual at Rest.
SBP: Systolic Blood Pressure of the Individual at Rest
RRF: Resting Respiration Rate
BMI: Body Mass Index
% FAT: Percentage of body fat

## 2.5 Participation of industrial engineering students in the development of the research project.

The participating industrial engineering students were linked to the research project through the formative research course, which in the development of their undergraduate studies corresponds to a level of training in basic research skills for the formulation of a degree project with which they can opt for the title of industrial engineer, this course corresponds to a ninth of ten semesters required to fulfill the academic program.

Thus, a requirement for the linking of students in the research project in the area of dermatoglyphics was to possess technological skills in the use of measurement tools, socialization skills to interact with other members, and cognitive skills in the collection, analysis and synthesis of statistical data from samples, aspects required according to the literature in the formation of engineering skills at the technological, socialization and emotional level for the year 2030 in the West; (Dahl, Tvenge, Assuad, & Martinsen, 2023; Ellingrud, Gupta, & Salguero, 2020)

Thus, the students participating in the research project with training in industrial engineering required a professional profile different from the traditional training in this nucleus of knowledge in Colombia. This aspect required the development of complementary competencies through multidisciplinary training sessions and practical actions framed within the scope of the project as referred to in the following sections of this document.

Once the students who met these requirements were selected, a team of nine people was formed, composed of one teacher from the health area, two teachers from the engineering area, five undergraduate students in industrial engineering, and five students from programs in the area of health as a professional in physical culture, professional sport, and recreation, These students started a first training from the health area to carry out the measurement process with the instruments available to measure the variables of height, weight, heart rate, respiratory frequency and blood pressure in each individual in an adequate manner.

Subsequently, the work team performed the measurements on the ninety individuals participating in the study after signing informed consent for the use of the information, which was explained by each member of the team in an empathetic manner and simple terms, an aspect that required social and emotional competence, this measurement was performed in a series of sessions in which each individual was measured in height and weight by an engineering student, while the measurement of the respiratory frequency and blood pressure was performed by a student in the area of health.

Additionally, once this process of measurement of physical characteristics had been carried out, each individual had each of the ten fingerprints of each of the fingers of their hands taken through a digital scanner, which was done by the teacher of the health area and the students of both study areas, to guarantee the legibility of the fingerprints and their correct digital storage in a digital file for each individual.

The previous process of capturing fingerprints required a second training process in scanner image reading skills, in which all teachers and students of both areas participated, for which it was necessary to formulate specifications for the development of this activity properly, to achieve a correct reading of the fingerprint and the storage of the information necessary for the study.

Then, based on these measurements, it was necessary to carry out a third training session from the health area, in which concepts such as the estimation of the body mass index were addressed, as well as the identification of the figures present in the fingerprints, such as radial and ulnar loops, arches and whorls, their forms of recognition and interpretation in digital files to consolidate the database of independent variables already stated earlier in this article.

Table 5. Competencies, skills, and tools desired in industrial engineering students for their participation in the research project.

| Competences | Skills | Tools |
|---|---|---|
| Technological Competencies | Measurement and data collection | Use scales, blood pressure monitors, measuring devices, fingerprint readers, etc. |
| | Use of Software | Watson Fingerprint Recognition Software |
| Socials Competencies | Communication Skills | Communicate clearly and effectively with participants, explaining the purpose of data collection, instructions for making measurements, and answering any questions or concerns from participants. |
| | Empathy and Cultural Sensitivity Ability | To interact with people from diverse cultures, backgrounds, and socioeconomic levels, demonstrating empathy and respect for individual differences. This is important to create an environment of trust and comfort during data collection. |
| | Ethics and privacy | Understand and adhere to ethical principles and privacy standards related to the collection and handling of biometric data. They must ensure the confidentiality of the information collected and obtain informed consent from participants before any measurements are taken. |
| | Ability to manage difficult situations | Prior preparation to deal with difficult or unexpected situations during data collection, such as identifying potential health problems or managing participants who may feel uncomfortable or anxious during the process. |
| Cognitive Competencies | Collaboration and teamwork | It is important that they can work collaboratively with other health professionals, researchers, or university staff involved in the data collection project, ensuring effective coordination and integrity of the data collected. |
| | Statistical Analysis | Strong understanding of statistical principles, including probability distributions, descriptive statistics, statistical inference, and multivariate techniques. This will enable them to perform exploratory data analysis and assess the significance of relationships between variables. |
| | Mathematical Modelling | Knowledge of mathematical modeling techniques, including linear and nonlinear regression, time series analysis, logistic regression models, and survival analysis, among others. This will allow them to develop predictive and explanatory models based on the data collected. |
| | Accurate recording and documentation skills | Rigorous recording and documentation of the data collected, ensuring that the information is complete, accurate, and organized for further analysis and use. |

Once the measurements of the physical characteristics, as well as the type of figures and number of characteristics of each of the ten fingerprints of the participants, each of the team members participated in the development of a database containing the necessary information to make a projection model of own conditions in the description of chronic noncommunicable disease, so that independent variables are derived from the measurement of weight, height, number of figures and type of figures as independent variables, as well as body mass index, diastolic and systolic blood pressure as dependent variables.

Once the database is consolidated, a fourth training session is carried out from the engineering area in which the topic of statistical projection models is dealt with through general linear models in which the criteria for information analysis are established such as reduction of coefficients, variance analysis and formulation of the general linear model, which is part of the set of knowledge proper to the study of industrial engineering. This aspect is consolidated in the objective of the project for its use and dissemination in the academic community interested in these topics. (Figure 1).

| -TRAINING PHASE | |
|---|---|
| -Engineering Area<br>Training in the use of Stat Graphics | -Health Area<br>Training in Biometric Measurements |

| -MEASURING PHASE | |
|---|---|
| -Engineering Area<br>Respiratory Frequency and Blood Pressure Measurement | -Health Area<br>Fingerprinting |

| -ANALYSIS AND MODELING PHASE | |
|---|---|
| -Engineering Area<br>Statistical Analysis and Mathematical Modeling | -Health Area<br>Dermatoglyphic Analysis and Recognition |

Figure 1. Main Phases and Activities of participation in the research project by area of knowledge.

# 3 Results

The research project was carried out with the participation of students of engineering and health, achieved at the end of the stage of analysis and synthesis of information collected from the participating individuals the following general linear model with which it is possible to predict the body mass index of each individual from the information of the number and type of figures present in the fingerprints:

## 3.1 Coefficient reduction

In this aspect of coefficient reduction through the analysis of four statistical measures of adjusted R-squared, unadjusted R-squared, Mallows Cp, and mean square of the error (MSE), it was possible to establish that the number of coefficients suitable for use in the statistical model to determine the body mass index used eighteen coefficients with an 84.8% explanation rate from the predictor variables.

## 3.2 Analysis of variance of the general linear model

After obtaining the sensitive variables of the multiple regression model, a regression analysis of the linear model is performed with these variables, obtaining a mathematical model that represents the data set. According to the calculation of the P-value in the analysis of variance table for BMI is less than 0.05, there is a statistically significant relationship between BMI and the predictor variables with a confidence level of 95.0%.

Table 5. Analysis of variance for BMI

| Source | Sum of Squares | Gl | Medium Square | F-Ratio | P-Value |
|---|---|---|---|---|---|
| Model | 234,511 | 18 | 13,0284 | 3,42 | 0,0211 |
| Residue | 41,9441 | 11 | 3,8131 | | |
| Total (Corr.) | 276,455 | 29 | | | |

### 3.3 General linear model for BMI prediction

The general linear model that explains a level of 84.8% of the body mass index from the fingerprint study is as follows:

IMC = 31,8544 + 1,42142*I1(1) + 1,956*I2(1) + 0,549131*I2(2) - 0,482455*I2(3) - 4,29804*I3(1) + 1,3485*I3(2) + 3,0337*I4(1) + 2,48367*I4(2) + 0,2508*I5(1) + 3,24892*I5(2) + 1,04156*I5(3) -1,93294*I6(1) + 0,3515*MDSQL1 - 0,0431056*MDSQL2 - 0,601223*MDSQL4 + 0,671739*MDSQL5 - 0,496272*MESQL1 - 0,51592*MESQL2

Where:

I1(1) = 1 if MDT1=2, -1 if MDT1=3, 0 in other case

I2(1) = 1 if MDT2=1, -1 if MDT2=4, 0 in other case

I2(2) = 1 if MDT2=2, -1 if MDT2=4, 0 in other case

I2(3) = 1 if MDT2=3, -1 if MDT2=4, 0 in other case

I3(1) = 1 if MDT3=2, -1 if MDT3=4, 0 in other case

I3(2) = 1 if MDT3=3, -1 if MDT3=4, 0 in other case

I4(1) = 1 if MET1=2, -1 if MET1=4, 0 in other case

I4(2) = 1 if MET1=3, -1 if MET1=4, 0 in other case

I5(1) = 1 if MET2=1, -1 if MET2=4, 0 in other case

I5(2) = 1 if MET2=2, -1 if MET2=4, 0 in other case

I5(3) = 1 if MET2=3, -1 if MET2=4, 0 in other case

I6(1) = 1 if MET4=2, -1 if MET4=3, 0 in other case

## 4 Conclusions

According to the development of this project and the statistical analysis of the results, where the general objective is to design a mathematical model for predicting the predisposition to non-communicable chronic diseases developed from data collected from a population of 400 students from higher education institutions in the city of Bogotá, with a sample of 90 individuals randomly selected, it is concluded that:

Engaging industrial engineering students in interdisciplinary field research holds paramount significance in their academic and professional development. Collaborative endeavors with experts across diverse domains, notably the healthcare sector, facilitate the cultivation of invaluable skills imperative for their future roles. Through such collaborative initiatives, students are not only equipped with effective interdisciplinary communication abilities but also adept at navigating disparate methodologies inherent in varied disciplines. This multifaceted exposure fosters a comprehensive comprehension of intricate challenges, thereby nurturing critical thinking, creativity, and innovative problem-solving approaches. Moreover, practical engagement in field research offers students tangible experiences, bridging the gap between theoretical knowledge and real-world applications. Consequently, these immersive learning experiences empower industrial engineering students to emerge as versatile professionals capable of addressing multifarious challenges within healthcare and beyond, catalyzing positive transformations through their innovative solutions.

During the evaluation and collection of dermatoglyphic data, a critical activity has been identified that prolongs the duration of the information collection sessions. This activity consists of individually taking fingerprints for each finger, which causes a delay in the session.

The process of selecting the most relevant and significant dermatoglyphic variables for predicting obesity has been fundamental to the development of this project. During this process, various dermatoglyphic variables were identified and analyzed for subsequent modeling in the statistical program Statgraphics. At the end of this process, twenty independent variables were selected, which refer to the number of ridges in the fingerprints and the types of existing patterns, and two dependent variables, which are BMI (Body Mass Index) and FAT% (Body Fat Percentage).

During the modeling of the selected variables using the Statgraphics program, the effectiveness of this tool as an optimal resource for statistical analysis was evident. Stat graphics proved to be a comprehensive tool that provides a wide variety of graphs and tables, significantly contributing to the analysis of the model performed. The graphs generated by the program allowed for a clear and concise visualization of the relationship between the variables, facilitating the interpretation of the results and the identification of relevant patterns or trends.

In the BMI variable model, it is evident that out of the twelve analyzed sensitive variables, two are significant for predicting obesity: MDSQL1 (right thumb) and MDSQL2 (Right Hand Index finger). Additionally, when analyzing the %FAT model, it is observed that the sensitive variables that this model yields are present in the variables of the BMI model. Out of the seven sensitive variables yielded by the %FAT model, two are significant for predicting the percentage of body fat, which are MDSQL4 (Right-Hand ring finger) and MDSQL5 (Right-Hand little finger). Therefore, it is concluded that these two variables are also related to predicting obesity in students from higher education institutions in Bogotá.

Industrial engineering students can play a crucial role in interdisciplinary integration with the healthcare sector through various strategies:

Process Analysis: Industrial engineers are trained to analyse and improve processes in different contexts. In the healthcare sector, this involves identifying areas of inefficiency in medical care, from patient admission to discharge, and proposing solutions to optimize workflows and reduce waiting times.

Supply Chain Optimization: Industrial engineering students can apply their knowledge of supply chain management to improve the distribution of medical supplies and medications, ensuring their availability at the right times and places. This is essential for ensuring effective and timely medical care.

Quality Management System Design: Quality principles and continuous improvement are fundamental in both industry and the healthcare sector. Industrial engineering students can help implement quality management systems in hospitals and clinics, ensuring that standards are met, and medical errors are minimized.

Application of Technology and Data Analysis: Technological advancements are transforming healthcare, and industrial engineers can contribute to their implementation and optimization. For example, they can develop information systems and data analysis tools to improve patient monitoring, medical record management, and clinical decision-making.

Design of Facilities and Medical Equipment: Knowledge of facility and equipment design are key skills of industrial engineers that can be applied in the healthcare sector. From designing hospitals and clinics to optimizing the design of medical devices, industrial engineering students can contribute to creating safer and more efficient healthcare environments.

Interdisciplinary collaboration with the healthcare sector is crucial for training industrial engineers. By integrating knowledge from both fields, industrial engineers can contribute innovative solutions to enhance healthcare systems' efficiency, safety, and accessibility. They can develop technologies and processes that optimize resource management, streamline workflows, and improve patient care outcomes through collaboration. This synergy between engineering and healthcare fosters innovation and addresses complex challenges facing the healthcare industry, ultimately benefiting society.

# 5 Recommendations

Considering the importance of this research work and based on the results obtained, recommendations are made for both teachers and students who wish to continue this line of research. In the fingerprinting activity, it is recommended to work with equipment that allows for the collection of fingerprints from more than one finger at a time, as this will streamline the process, reducing the time required for data collection sessions.

For researchers and teachers, it is recommended to implement a program containing a Machine Learning code, which will enable them to analyse fingerprints in an agile and rapid manner, as this process is the most time-consuming when done manually. It is important to be rigorous in ensuring that all requested data are obtained to avoid the culling of many individuals, which could result in a lack of a robust and consolidated database for research purposes. Students who wish to continue with this line of research are advised to review studies related to dermatoglyphics and statistics to better understand and analyse the results obtained from the statistical program.

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# Active Learning and New Technologies: Towards Better Learning

Jens Myrup Pedersen[1], Katherine Ortegon[2], Henry Arley Taquez Quenguan[3], Angelica Burbano Collazos[2]

[1] Cyber Security Group, Department of Electronic Systems, Aalborg University, Denmark
[2] Facultad de Ingeniería, Diseño y Ciencias Aplicadas, Universidad Icesi, Cali, Colombia
[3] Decanatura de Innovación Educativa y Fortalecimiento del PEI, Universidad Icesi, Cali, Colombia

Email: jens@es.aau.dk, kortegon@icesi.edu.co, hataquez@icesi.edu.co, aburbano@icesi.edu.co

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**Abstract**

Digitalisation has revolutionised the way many areas of our societies work, but until recently only impacted university education to a limited extent. However, after the pandemic it has become clear for decision makers, professors, and students that the technology has a lot to offer, and that digital technologies can support teaching and learning activities in many ways, from improved collaboration tools, to the possibility of online meetings/classes, via interactive tools that can be used in the classroom and all the way to data-driven approaches for predicting students failing exams or dropping out of their studies. With this paper, we aim to support both professors and decision makers in navigating the plethora of digital tools, keeping in mind that the main purpose is to create meaningful and challenging learning experiences for the students – rather than trying out new technology for the sake of technology. We first present a taxonomy for different types of tools, to differentiate between e.g. administrative tools, collaboration tools, communication tools, databases, hardware, artificial intelligence, virtual/augmented reality, streaming tools, tools for interactive teaching, and learning management systems. Following this, we discuss how the different categories of tools can be used to enhance our teaching-learning environments with particular focus on creation of active learning experiences, didactical considerations, and on the impact of professor and student roles. Many of the technologies enable the students to work and learn together with their peers, which is positive, but it also changes the role of the professor in the direction of being more of a facilitator, a guide. Moreover, the technologies also support the creation of problem-based learning situations not only because students get access to learning resources when they need them but also because the new technologies support collaboration across organisational and geographical boundaries. The new tools can also be used to simulate realistic environments and experiments that were not possible before and will help universities to cope with new reality supported by digitalisation.

**Keywords**: Active Learning; Engineering Education; Learning Technologies; Problem Based Learning.

## 1 Introduction

This study is motivated by a recent reflection on the use of technology in universities across Latin America, which indicates the use remains low even after the Covid-19 pandemic (Metared TIC, 2023). Technology has a lot to offer to facilitate the learning process and faculty needs help navigating the current landscape (Morales-Urrutia et al., n.d.). Unfortunately, faculty are often on their own when it comes to the use of technology for teaching and learning, and it is not uncommon to see each faculty member starting from scratch with their own set of tools including both getting familiar with the technicalities, as well as trying to fit it into relevant didactical contexts. While this approach appeals to some, it does not provide for a wider uptake of technologies and the advantages its use can provide. With this paper, we hope to make it easier for a broader group of faculty to embrace new technologies and use them in ways that make sense also didactically.

The main contribution of the paper is that it provides a useful overview for faculty, who would like to improve teaching and learning through the use of new technologies. This is achieved by first proposing a taxonomy to classify tools according to their use, considering an active learning environment, followed by examples of how the different categories of tools can be used to enhance teaching and learning environments. Then the change in roles of both professors and students is addressed, before closing the paper with discussions and conclusions.

## 2 Taxonomy

Based on the proposed classification of technological resources presented by María & Cacheiro (2011), in which the resources are classified as resources for information, resources for collaboration and resources for learning, and also on the proposed functions that tools could have, we propose a taxonomy that can help faculty to navigate the landscape of technologies and also to reflect on its use. We also consider the fact that Covid-19 did expose us to a myriad of technologies that complement the previous classification and left us with an ample set of options which are hard to navigate. We propose seven dimensions for our taxonomy which we will refer to as ACTIVE:

**A = Activation** or engagement. This dimension describes tools used to activate metacognition and engage students. This can be both inside and outside of the classroom. It can include gamification and digital boards, where students are contributing, but it can also be tools that facilitate discussions between students. It also includes tools used for reflection.

**C = Communication**. This dimension includes all tools that facilitate information sharing and the creation and use of learning resources to provide meaningful communication among team members.

**T = Teamwork**. This dimension includes all tools that facilitate the joint construction of knowledge as well as discussion or consensus when needed. Teaming might be disciplinary or interdisciplinary.

**I = Interactivity**. This dimension includes all tools that facilitate simulation, observation, exploration and experimentation between two or more people or generative AI tools.

**V = Virtualisation.** This dimension includes all tools that allow students and professors to interact in a space that is different from the physical classroom.

**E = Evaluation.** This dimension includes all tools that facilitate formative or summative, graded or non-graded, individual or group, self or peer, feedback or assessment before, during or after classes.

Working with the taxonomy leads to many reflections and discussions among the authors, which are important to keep in mind when reading through the dimensions. We observe a trend, where different classes of the taxonomy are merging into tool suites, which cover multiple (or all) aspects of learning and/or project work - one early example being the ILICE platform, which attempts to support all stages of projects in the context of Problem Based Learning (Sørensen & Pedersen, 2018). At the same time, there is also a movement towards integration of standalone tools. One example of many is the integration between Github and Slack.

## 3 Enhancing Teaching and Learning environments through technology

Enhancing teaching and learning environments (TLE) is a continuous challenge for professors. When professors were asked about their reasons to implement changes in their courses or changes in their teaching practices, it was found that there are three main drivers: First, the coherence between the courses and the educational purposes of the program. In other words, the alignment between the course objectives and the competencies of the program has gained importance not only because of the accreditation system in place but also as a result of understanding the importance of instructional alignment. Second, the response to claims identified by students as part of the need for developing courses that are meaningful along their majors and courses that will prepare them to solve real-world problems. Third, professors expressed a genuine interest in innovating and implementing what they have learned during pedagogical training (Fernandez Rodriguez & Gutierrez Iglesias, 2021).

Despite the reasons behind its implementation, when professors decide to integrate technological tools in their teaching and learning environments, they should reflect on the following: what is the **purpose** of using this tool or technology in my course? *How does this tool or technology contribute to the student's achievement of the course and program objectives?* And more importantly, *do students understand the contribution and value of these tools in their learning process?* This reflection will cause professors to avoid the use of tools or technologies for the sake of technology and rethink professors and students' role relative to those tools and technologies.

Considering the ACTIVE taxonomy, examples of how the technology can enhance the TLE are presented for each dimension in Table 1.

Table 1. Examples of teaching and learning enhancements in class based on technology used.

| **Taxonomy** | **Examples of Technology/Tools** | **Examples of Enhancement of the TLE** |
|---|---|---|
| **A** | Search and Information Publishing Tools (Google, Bing).<br>Chatbots (ChatGPT, Copilot, Gemini, Claude, Mistral).<br>Academic databases (Scopus, Web of Science, Science Direct). | Asking students to compare information from chatGPT relative to their previous knowledge.<br>Asking students to identify their knowledge gaps and navigate DB and search engines to have a new understanding. |
| **C** | Video conference tools (Zoom, Teams. Meet).<br>Instant messaging tools (Slack, Discord, WhatsApp).<br>Learning Management Systems (Moodle, Canva, Bridge Space). | Creating interdisciplinary or multicultural teams to solve problems.<br>Facilitating blended environments (physical and virtual).<br>Organize communication within smaller and larger teams in a structured way.<br>Support community building, by providing a virtual communication space less formal than e.g. emails, but more organised than just chats. |
| **T** | Digital boards (Miro, Mural, Jamboard)<br>LaTeX editor Tool (Overleaf).<br>Platforms for version control (Github).<br>Prototype generation tools (Figma).<br>Cloud-based text processing tools (Google docs).<br>Graphic design creation tools (Canva, Geneally). | Creating interdisciplinary or multicultural teams to solve problems.<br>Using MIRO templates facilitates the co-construction of ideas or solutions for a problem. Information is accessible any time and can be modified in real-time.<br>Shared documents with e.g. space for comments and discussions make it possible to construct knowledge together both synchronous and asynchronous. |
| **I** | Digital boards (Padlet, Jamboard).<br>Real-time response systems (Mentimeter, Socrative, Kahoot). | Anonymously, ask students to identify their knowledge gaps or teamwork weaknesses during a project.<br>Anonymity will encourage students to participate freely and honestly. It facilitates building upon questions and inputs from other students. |
| **V** | Virtual, augmented, and mixed reality tools (Spatial, Meta spark).<br>Video streaming services (YouTube).<br>Podcast tools (Podomatic).<br>Learning Management System (Google Classroom).<br>Digital boards (Open board).<br>Virtual hackerlabs (Haaukins). | Allowing students to decide which deliverable format would be better. This will enhance their autonomy in decision making and argument skills as well as their creativity.<br>Makes it possible to use visual content, sometimes in active formats such as with "virtual laboratories". |
| **E** | Real-time response systems (Mentimeter, Socrative, Kahoot, Quizizz, Google forms).<br>Tools for creating rubrics (RubiStar). | Use these tools when needing to tune the class, providing instant feedback or allowing students to self-evaluate their experience of level of understanding achieved. |

While the table provides a list of non-exhaustive examples, we believe it demonstrates an approach of how explicitly formulated goals for improving the TLE can motivate the introduction of relevant tools to support these goals. In our experience, having clear goals - which are communicated to both students and other faculty members involved in a given course or learning experience - is a crucial part of achieving the goals.

In the next section, we address how the use of different technologies change the roles of both professors and students in the learning situation.

# 4 Professor´s and Student´s roles in TLE supported by technology

The role of professors and students has been in continuous evolution since every discipline and every techno-pedagogical framework requires an adjustment in each one of the roles. For instance, moving towards flipped classrooms required to change from the professor-centred to the student-centred model. This had a great impact on the professor’s role when deciding the relevant readings to be assigned before class and re-designing the experience during the class to achieve the learning objectives. On the other hand, students move from a passive role during the class to an anticipated active role before and even after the class time.

Another example, which demonstrates the need for clarifying the professor role, is the use of document sharing platforms in a PBL context: What is expected from the supervisor/facilitator: Should he or she simply give feedback to drafts and worksheets sent from the students to the supervisor, or is the supervisor equipped with access to the shared documents and expected to participate more actively and continuously in the writing process, now that he/she has access to both read, comment and edit directly in the documents?

We encourage faculty members to consider these roles when designing teaching and learning with the use of new technologies, and to make them explicit also to students and potential co-faculty members along with the goals presented in the previous section. This avoids students being confused or frustrated because they are unsure what they should do, what is expected from them and - eventually - how it can affect their gradings.

Table 2 suggests potential roles under the ACTIVE taxonomy highlighting that professors are transitioning towards facilitators of learner´s processes and students are transitioning towards independent self-regulated learners. What is key in every field of the table is that both students and professors are aware of their roles, even when roles are changing compared to previous learning environments.

Table 2. Professor´s and Student´s roles regarding ACTIVE learning technologies

| Taxonomy | Professor´s Role | Student´s Role |
|---|---|---|
| A | To design TLE that challenges students and triggers their critical thinking beyond these tools. | To identify and complement their knowledge gaps with the available tools while keeping a critical thinking relative to the findings. |
| C | To select the proper technology according to student´s possibilities. | To suggest tools with which they are familiar or to train accordingly. |
| T | To design TLE that encourages students to share, discuss, and agree on teams. | To have a joint construction that is more powerful than the individual one. |
| I | To provide timely and meaningful feedback | To be participative in an objective and honest manner |
| V | To study their audience and highlight the importance of deeper comprehension beyond virtual environments. | To take the ownership for their learning, self-directing their process and self-regulating their pace. |
| E | To design formative, summative, graded and non-graded assessment opportunities. | To participate actively and critically against the level of learning achieved. |

In particular, with respect to AI based technologies, we are questioning what new skills will be required in the AI era to support students in becoming metacognitive involved self-regulated learners (Ka Yuk Chan & Tsi, n.d.), since the same technology could serve different purposes. Also, we are questioning whether AI will replace the role of professors or will complement us in our process of guiding students on their learning journey.

# 5 Discussion

Nowadays, it is impossible to deny the high impact of technology in the TLE. However, more than ever we have to reflect not only on how to use it, but more importantly why to use it or why not. A wrong use of technology can discourage students and affect the metacognition process since the students will not understand the purpose of its use, or how to use it to better serve her or his learning process. This can lead not only to unhappy and frustrated students but can also discourage both the faculty involved and other faculty members in taking up and experimenting with new technologies. University environments can be conservative, and stories of failed experiments can confirm a reluctance of change among faculty members.

Currently, we as professors tend to use ICT tools during class to avoid bored students. However, its integration starts from the course design. Facilitators must define and explore which technologies really contribute to the expected goals, which technologies could be used during the class and which technologies could be useful at the closing or even after class. Some of the tools require planning in advance, the acquisition of software licences, or the use under certain constraints.

The Information and Communication Technologies (ICT) and Artificial Intelligence (AI) currently stand as fundamental allies or tools in educational processes. When employed appropriately within relevant contexts, ICT and AI act as facilitators in mediating between students, teachers, and the curriculum (Coll, 2004).

On one hand, interaction in digital environments, instant communication, and access to digital resources promote exploration and connection among diverse perspectives, innovative ideas, and challenging mechanisms of action. On the other hand, the digital recording of communications and learning processes offer valuable resources for fostering metacognitive reflection on the progress and challenges experienced during the learning process, as well as making pedagogical and didactic decisions based on data (Dai, Liu, & Lim, 2023).

Moreover, the integration of artificial intelligence into learning processes can become a strategic actor in stimulating thinking, as AI goes beyond technical functions and communicative mediations by including cognitive abilities such as pattern recognition, automation of thought processes, and analysis of convergences and divergences. This implies that AI can generate spaces for reflection on what has been learned, for collaborative creation, becoming an interlocutor of one's own thought through effective and creative human-AI communication (De Haro Olle, 2024).

Likewise, the integration of AI into the learning process favours the recognition of students' experiences, as personalised learning situations can be created to adapt to their needs and connect their previous experiences with the construction of new knowledge with meaning and significance.

By extending beyond the conventional classroom, these tools broaden spatial and temporal boundaries, which can improve interaction, collaboration, and more precise feedback. The appropriate use of ICT+AI resources can stimulate the design of enriched and flexible learning environments that adapt to the particular needs of each student, fostering interaction between teachers and students (Samoylenko et al., 2022).

Furthermore, it is important to consider that the incorporation of ICT and AI is also a way to value and recognize students' previous experiences with technology and their experiences in an increasingly digital and interconnected world. To harness this potential, it is important to intentionally integrate ICT and AI into the planning of learning situations to identify, for example, the most relevant contexts for their application and make decisions that allow these technologies to act as enhancers of thinking, and never as replacements. It is necessary, therefore, to develop digital competencies that transcend their technical dimension towards a critical perspective of technological development that enables addressing the challenges posed by AI in aspects such as intellectual production, equity, discrimination, environmental impact, and collaboration with others (Universidad Icesi, 2023). In this regard, a pedagogical-technological approach is required that allows for critical, responsible, creative, and effective interaction with ICT + AI tools in learning, thinking, and experience processes.

### ICT tools and the Generation of Teaching Practice Knowledge

ICT enables information to flow constantly between the interactions of a learning experience, and for this to occur, it is required that such information be made explicit.

For the proposed taxonomy dimension A, C and T are related to the creation of the learning environment. This process of transitioning from a teacher's tacit knowledge to explicit knowledge about what is taught and how it is taught allows for more rigorous planning and, in turn, enables more precise reflection on what happens in a classroom.

Specifically, this process of transitioning from tacit to explicit knowledge for teachers contributes to the creation of clearer instructions for students and the development of digital educational content. Furthermore, it contributes to the collective construction of knowledge derived from the implementation of a learning experience. Iliško et al. (2010) introduce the term 'teacher-researcher,' which 'characterises a reflective professional motivated to identify and address problems in their praxis' (p. 53). In this sense, the teacher is positioned at the center of knowledge production in the professional context of the classroom, with the purpose of: improving teaching practices, better understanding their actions, and thus, reclaiming their voice and making a difference (Iliško et al., 2010). In this way, the collective construction of such knowledge can range from personal and group reflective teaching practices to socialisation in academic events and the production of knowledge in education journals within the discipline.

### ICT tools and the Learning Assessment Process

The assessment process in a learning active experience is embedded within it; that is to say, it is not an element added at the end, but rather an integral part of it from its conception, as assessment is understood as an experience for learning with others.  For the proposed taxonomy, dimensions I, V and E are related to the assessment process.

In this sense, feedback is a fundamental piece, as it allows the student to progress not only in their cognitive and procedural knowledge but also in their sensitivity and human development. Specifically, timely and quality feedback that is used for student advancement in their process becomes necessary. Thus, the appropriate use of tools and technological resources stimulates the design of new flexible learning environments that adapt to the current needs of students and foster interaction between students and educators, thereby opening up new opportunities in the educational process (Samoylenko et al., 2022) by allowing the management of information flow in a learning experience, contributes to making such feedback information real-time, more precise, and explicit, thus creating contexts for the student to use it and also develop abilities for self-assessment and peer evaluation. Therefore, according to Miller & Staley (2021), timely feedback from both teachers and peers allows the student to reflect on their educational process, giving meaning to their thoughts, emotions, and experiences in the learning process.

## 6 Conclusions

This paper discusses the intrinsic relationship between technology and active learning emphasising the need of having clear goals and objectives about why to use it and how the TLE needs to be adapted to incorporate that technology. To facilitate this process, a taxonomy is presented in order to recognize the type of competencies the professor would like to develop. Likewise, the changes in the TLE environment and changes in student and professor´s roles are detailed.

It is also important to consider that the taxonomy presented here is generic and that for each discipline, specific ICT and AI tools can provide meaningful experiences in each of the proposed dimensions. The taxonomy can be enriched, and it will continue evolving along with the rapid changes in technology but the main essence remains, the tool has to be aligned and it requires a purpose.

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# Towards an Innovative Framework for Teaching Electron Configuration in Chemistry Courses Using Analogies

Javier Ramírez-Angulo[1], Josefina Castillo-Reyna[2]

[1,2] Tecnológico de Monterrey, Escuela de Ingeniería y Arquitectura

Email: jangulo@tec.mx, jocastillo@tec.mx

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**Abstract**

This paper explores the possibility of using a simple analogy based on a city with numbered streets and houses with features as a teaching strategy for electron configuration in chemistry courses. The analogy was designed to provide students with an easily understandable framework to help them understand the distribution of electrons within atoms. In this analogy, each numbered street represents an energy level, while the houses on the streets symbolize different types of energy sublevels. The rooms in the houses are associated with orbitals. The hierarchical structure of streets and houses facilitated the distinction between energy levels, energy sublevels, and orbitals. The results of using this analogy were very positive. A significant improvement was observed in the students' ability to write the electron configurations of various chemical elements and to distinguish between energy levels, sublevels, and orbitals. The analogy was successful in clarifying concepts that can be complex or confusing, providing students with clarity and confidence in understanding electron configuration. Specifically, this paper highlights the effectiveness of using a simple analogy as a pedagogical tool to improve learning outcomes in teaching this chemistry topic.

**Keywords**: Analogy; Educational Innovation; Electron Configuration; Higher Education

## 1 Introduction

As a fundamental concept in chemistry, electron configuration is the cornerstone for understanding several other topics in the field (Brown & May 2004). It is a central aspect of the general chemistry curriculum from the early stages of education in middle school to advanced courses in professional education (Russell & Larena, 1987). Although initially abstract and perhaps daunting to students, mastery of electron configuration is essential for delving into more complex topics within chemistry (Chang, 2002). Therefore, finding appropriate teaching strategies to help students understand this topic and write the electron configuration of a given chemical element can be helpful in both theoretical and laboratory courses to facilitate their learning (Ramirez, 2017).

Understanding electron configuration lays the groundwork for comprehending the structure and behavior of atoms, forming the basis for exploring the periodic table of elements (Eichinger,1968). The arrangement of electrons in different energy levels and sublevels directly correlates with an element's position in the periodic table and its chemical properties. For example, the periodic trends in atomic size, ionization energy, and electron affinity can be explained by variations in electron configuration across periods and down groups (Kurushkin, 2015).

Moreover, electron configuration is not a standalone concept, but it's intimately linked to the formation of chemical bonds (Brown & May, 2004). As we delve into the topic, we'll see that knowledge of electron configuration is crucial for understanding how atoms interact to form molecules through ionic bonding, covalent bonding, and metallic bonding (Chang, 2002). The sharing or transfer of electrons between atoms, which underlies these bonding types, can be rationalized by considering the stability achieved through achieving noble gas electron configurations.

Furthermore, electron configuration plays a pivotal role in understanding hybridization, particularly in molecular theory and bonding (Kurushkin, 2015). Hybridization involves mixing atomic orbitals to form new hybrid orbitals, which in turn influences the geometry and bonding properties of molecules. By understanding the electron configuration of the atoms involved, students can more accurately predict the hybridization schemes and molecular shapes.

Since electron configuration is a foundational concept in chemistry education, it has far-reaching implications for understanding the behavior of atoms, the periodic table, chemical bonding, and molecular structure (Ramírez, 2017). By employing effective teaching strategies that cater to diverse learning styles and incorporating practical applications, educators can empower students to master this essential topic and pave the way for further exploration in chemistry (Orgill & Bodner, 2004). Using analogies in teaching specific chemistry topics, such as electron configuration, can be a very effective teaching strategy that facilitates understanding (Thiele & Treagust, 1992).

## 2 Background

Due to its abstract nature, teaching chemistry, particularly the concept of electron configuration, is often challenging for both teachers and students (Orgill & Bodner, 2004). Analogies are powerful tools for simplifying complex concepts by drawing parallels to familiar phenomena (Huependo, 2021). This abstract examines the effectiveness of analogies in teaching electron configuration in chemistry education.

Electron configuration is a notation used to describe the arrangement of electrons in an atom's electron shells (Brown & May, 2004). It's typically written as a series of numbers and letters representing the energy levels and sublevels where electrons are found (Russell & Larena, 1987).

The electron configuration of an atom is typically represented using a notation that indicates the number of electrons in each energy level and sublevel (Kurushkin, 2015). The main energy levels are often labeled with principal quantum numbers (n = 1, 2, 3, etc.), which represent the energy of the electrons. Each level contains one or more sublevels, containing orbitals. These orbitals have different shapes and orientations in space, as described by the angular momentum quantum number (l), which determines the shape of the orbital, the magnetic quantum number (m), which determines the direction the orbital faces, and the spin quantum number (s), which represents the spin of the electron (Chang, 2002).

The electron configuration notation follows a specific format. It begins with the principal quantum number (n), followed by the sublevel designation (s, p, d, f), and the number of electrons in that sublevel (Eichinger, 1968). For example, the electron configuration of hydrogen (H) is $1s^1$, indicating that it has one electron occupying the 1s orbital. Helium (He) has an electron configuration of $1s^2$, as it has two electrons filling the 1s orbital. Let's take another example, carbon (C), which has an electron configuration of $1s^2\ 2s^2\ 2p^2$. This means that carbon has two electrons in the 1s orbital, two in the 2s orbital, and two in the 2p orbital (Brown & May, 2004).

As the atomic number increases, more electrons are added to the atom, filling the available orbitals according to certain rules. The Aufbau principle states that electrons fill the lowest energy orbitals first before moving to higher energy levels (Chang, 2002). This means that the 1s orbital is filled before the 2s orbital, and so on. Hund's rule dictates that within a sublevel, electrons will occupy individual orbitals with parallel spins before pairing up. This is why, for example, the 2p orbital is filled with one electron in each of the three orbitals before any of them pair up (Kurushkin, 2015). The Pauli exclusion principle states that no two electrons in an atom can have the same set of quantum numbers, meaning each orbital can hold a maximum of two electrons with opposite spins. This is why, for example, the 1s orbital can hold a maximum of two electrons, one with spin up and one with spin down (Eichinger, 1968).

The periodic table, a powerful tool in chemistry, doesn't just organize elements based on their atomic number, which corresponds to the number of protons in the nucleus (Russell & Larena, 1987). It's a guide that helps us understand electron configurations (Brown & May, 2004). Elements within the same group or column of the periodic table often have similar electron configurations due to their similar chemical properties. By understanding the periodic table and its relationship to electron configurations, you can navigate the world of chemistry with confidence (Huependo, 2021).

Understanding electron configuration is not just a theoretical concept, but it has profound practical applications in predicting an element's chemical behavior (Chang, 2002). This knowledge is not just crucial, but it's the key to understanding how elements interact with each other, including their ability to form bonds with other atoms and molecules (Ramírez, 2017). Furthermore, it's the foundation that helps explain the periodic trends observed in the properties of elements across the periodic table. In essence, electron configuration is a fundamental concept in chemistry, providing valuable insights into the structure and behavior of atoms, and its understanding is key to mastering the subject (Brown & May, 2004).

## 2.1 Analogies

Analogies are employed as cognitive bridges, connecting unfamiliar concepts with familiar ones (Orgill & Bodner, 2004). In the context of electron configuration, which involves understanding the distribution of electrons within atomic orbitals, analogies can aid in visualizing abstract concepts (Thiele & Treagust, 1992). For instance, the planetary model analogy compares electrons orbiting the nucleus to planets orbiting the sun. This analogy simplifies understanding electron distribution by likening it to familiar celestial motions (Huependo, 2021).

Furthermore, the shell and subshell analogy break down electron configuration into hierarchical levels, akin to the organization of nested Russian dolls. Each shell corresponds to a different energy level, while subshells represent distinct orbital types within each shell (Kurushkin, 2015). This analogy facilitates the comprehension of electron distribution patterns within atoms by providing a tangible framework (Brown & May, 2004).

Moreover, analogies aid in comprehension and foster engagement and retention among learners (Orgill & Bodner, 2004). Analogies capture learners' interest and stimulate their curiosity by tapping into familiar contexts (Huependo, 2021). For instance, the "building blocks" analogy likens electrons to construction workers filling energy levels analogous to floors in a building. This analogy not only elucidates the concept of electron distribution but also instills a sense of ownership in learners as they construct mental models of atomic structure (Thiele & Treagust, 1992).

Additionally, analogies can be tailored to address learners' misconceptions or challenges (Ramírez, 2017). For example, the "bus analogy" addresses the misconception of electrons occupying discrete orbits by likening them to passengers boarding a bus. Electrons can occupy any available seat (orbital) within a particular energy level but cannot exist between seats (orbitals). This analogy clarifies the probabilistic nature of electron distribution, dispelling common misconceptions (Huependo, 2021).

Furthermore, analogies can be adapted to suit diverse learning styles and preferences, demonstrating the inclusivity and considerateness of the teaching approach (Orgill & Bodner, 2004). Visual learners may benefit from spatial analogies such as the "spiral staircase" model, which illustrates the arrangement of electron orbitals in three-dimensional space (Kurushkin, 2015). Auditory learners may find resonance in musical analogies, where electron orbitals are likened to harmonic frequencies within an atomic orchestra (Brown & May, 2004).

In conclusion, analogies are valuable tools for elucidating complex concepts such as electron configuration in chemistry education. By leveraging familiar contexts and visual metaphors, analogies facilitate comprehension, engagement, and retention among learners. Educators are encouraged to harness the power of analogies to demystify abstract concepts and cultivate a deeper understanding of chemistry among students.

## 3 Methodology

To use an analogy that would help chemistry students understand the topic of electron configuration, they were told to imagine a city whose streets are numbered as in some towns and that as the number of the street would increase, the size of the street would also increase, that is, street 1 < street 2, < street 3, etc.

They were also told that in each street there could only be a number of houses equal to the number of the street, i.e. in street 1 there was only one house, in street 2, two houses, in street 3, three houses and so on. Then they were told that there were only four different types of houses, depending on the number of bedrooms or alcoves inside and all with odd numbers starting from the simplest with one bedroom, then with three, five and seven alcoves.

Representing this schematically, it would look something like this for the first four streets:

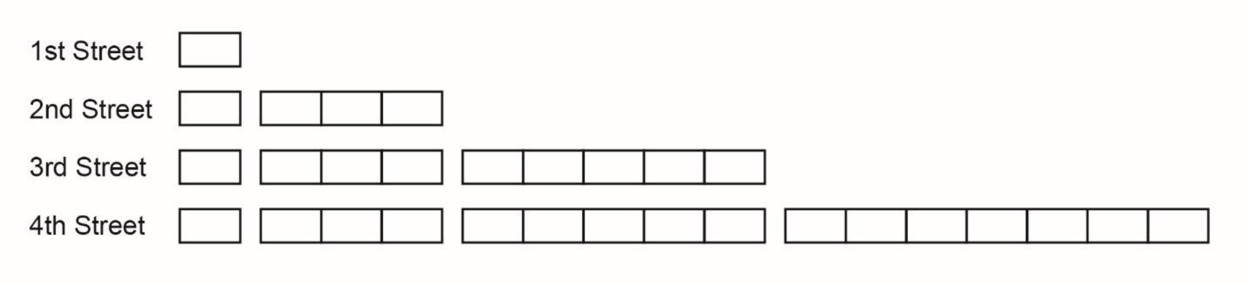


Figure 1. City with numbered streets

At this point, it was clarified that each bedroom had two single beds with opposite headboards. This is why each sleeping room could accommodate a maximum of two people if one lay down in one direction and the other in the other direction. However, there could also be only one person or none, as shown in Figure 2.

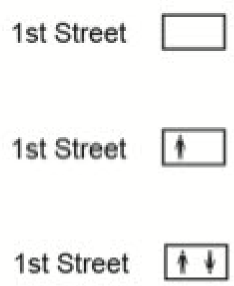


Figure 2. Bedroom in a house on First Street

The students were then asked how many people at most could be in each type of house, to which they all answered quickly, 2, 6, 10, and 14, which was used to try to name them in some appropriate way. They agreed the smallest house was a "simple" house, and that is what it was called; the one with three bedrooms or six people was said to look like a student house of a polytechnic university , so it was called "poly" house, the five-bedroom house was called "decade" house, because of the number of people it could have and the biggest one, which seemed to be made to house a football team, was called "football" house.

It was not difficult for the students to describe that in this city, they could distinguish that there was a simple house on street 1, a simple house and a poly house on street 2, a simple house, a poly house, and a decade house on 3rd Street and finally a simple house, a poly house, a decade house and a football house on 4th Street.

Then they were asked if people were coming to stay in that town, would they indicate by the street number and the type of house where the first, the second, the third would arrive and so on, the students answered that the first person would do it in the simple house on street 1, the second person in the same house and on the same Street, but they were reminded, since they were in the same room, since the simple house only has one, they had to go to bed in opposite directions, something similar happened for the third and fourth person who entered the simple house on 2nd Street, and continued with the fifth person in the poly house on 2nd Street, but when referring to the sixth person they said that he entered the same first bedroom of the poly  house on 2nd Street in the opposite direction, at that moment it was clarified to them that since there were still two empty bedrooms in that house simple, the most appropriate thing was for that sixth person, the second to enter the poly house on 2nd Street, to stay in the next room, the seventh person could still do something similar and take a bedroom alone, but already the eighth person  would have to share his room with the first person who entered that house, that is, with the fifth person who entered the town and so on. The schematic would look something like this, using arrows to facilitate the representation of people.

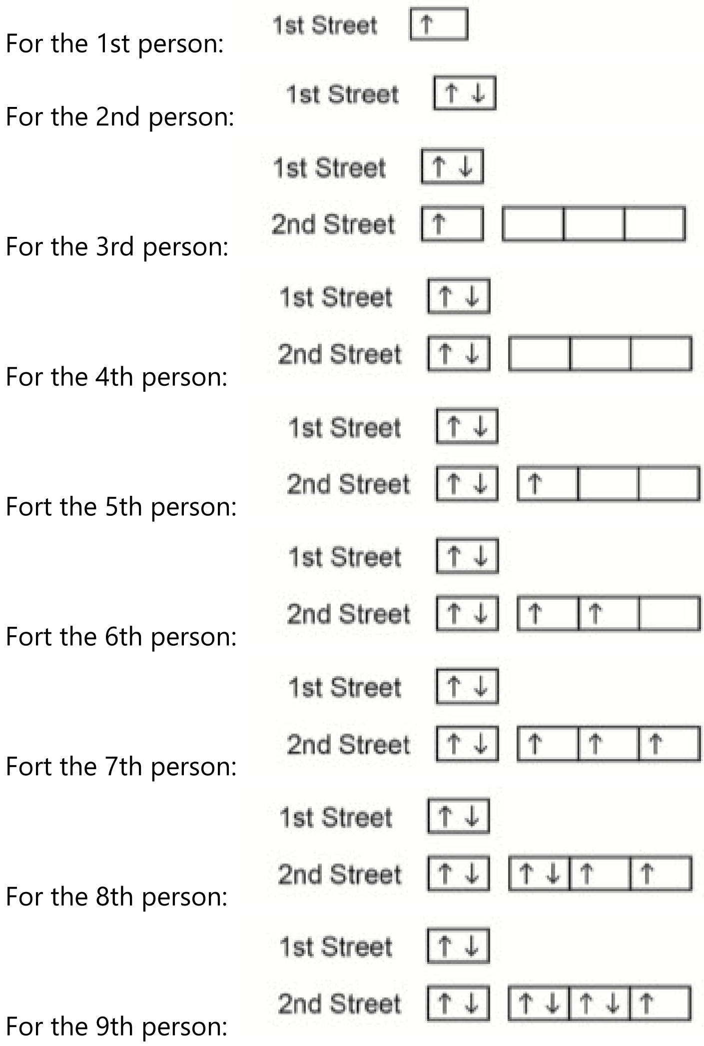


Figure 3:  1st to 9th person

In this way, one filled up the houses until the fifteenth person, who arrived at the third bedroom of the poly house on 3rd Street, which appeared as follows:

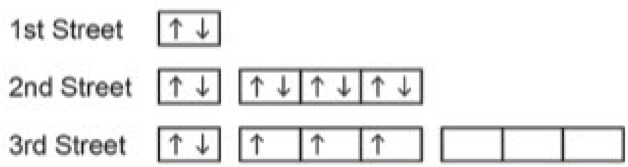


Figure 4: 1st to 15th person

Next, one told the students that they could avoid drawing the diagram of streets and houses if they only showed how many people there were in a given home and street, always indicating the street number, then the name of the house, and then the number of people in it in this way:

1 simple 2

2 simple 2    2 poly 6

3 simple 2    3 poly 3

After this, one told them that to simplify the writing, one would write only the first letter of each house and that the number of people in them would be written as an exponent like this.

1 $s^2$

2 $s^2$    $2p^6$

$3s^2$    $3p^3$

> Writing it straight would look like this: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^3$. One asked the students to do the same from person number 1 to 18 and to indicate in each case how many bedrooms were full, half complete, and empty.

When one noted that the students had understood this whole concept of everyday life, the topic of the structure of the atom began to be discussed, emphasizing that the electrons were distributed outside the nucleus in energy levels that were called levels 1, 2, 3, etc. in which there were energy sublevels, known as s, p, d and f, which in turn contained orbitals, where there could be up to two electrons, as long as they rotated in the opposite direction, the s sublevel only had one orbital and therefore both a maximum of 2 electrons, the p sublevel, three orbitals, that is, a maximum of 6 electrons, the d, five orbitals with a maximum of 10 electrons and the f, seven orbitals with a maximum of 14 electrons. One explained that this representation of the arrangement of electrons in energy levels and sublevels, which an atom had given by its atomic number, was called electron configuration.

# 4 Results

In the assessment, a substantial portion of students showcased an impressive grasp of the analogy, effectively linking the street number to energy level, type of house to energy sublevel, room to orbital, and electron to person. Moreover, they exhibited comprehension regarding the opposite spins of electrons within orbitals, drawing a parallel with the sleeping positions of individuals in bedrooms.

This pedagogical approach not only facilitated students in constructing electron configurations for various chemical elements but also equipped them with the necessary skills to explore related topics such as quantum numbers, periodic properties, Lewis structures, and chemical bonds.

This instructional strategy's efficacy in elucidating seemingly abstract concepts like electron configuration may stem from its alignment with the constructivist paradigm (Hernandez, 2008), inherent in metacognitive processes. Students actively construct their understanding by establishing connections between familiar analogies and abstract concepts, thereby enhancing metacognitive awareness and knowledge retention.

Nevertheless, a minority subgroup comprising approximately 10 to 12% of students voiced dissent regarding this teaching methodology. They articulated concerns about confusion between the core topic and its analogical representation, advocating for a more direct instructional approach. Some students preferred to abstain from analogies altogether, while others acknowledged their initial comprehension of the city-based analogical model but encountered difficulties during examinations. They lamented the need for questions framed explicitly within the analogical framework, leading to disparities between initial understanding and exam requirements.

These findings underscore the importance of a balanced approach in integrating analogies within pedagogical practices. While analogies can significantly enhance comprehension and engagement for most students, it is crucial to address the concerns of the minority subgroup. Educators should aim for clarity in transitioning between analogical representations and core concepts while carefully incorporating analogies into assessment strategies to align with students' expectations and comprehension levels. This approach can optimize the benefits of analogical teaching while mitigating potential drawbacks for a diverse student population.

# 5 Conclusions

Using a straightforward analogy, likening the electron configuration to a city or town with numbered streets and houses with one, three, five, and seven rooms has proven to be a remarkably effective teaching strategy.

This approach, which is part of most general chemistry programs, helps to demystify the complex topic of electron configuration. The city analogy strategy, a simple yet powerful tool, compares electron configuration to the structured layout of a bustling city or tranquil town. This straightforward approach, seamlessly integrated into the curricula of most general chemistry programs, serves as a beacon of clarity amidst the labyrinthine complexities inherent in the study of electron configuration.

Whether you're a university scholar, a chemistry enthusiast, or simply someone with a curious mind, the city analogy strategy welcomes you. This strategy, meticulously refined and rigorously tested within the hallowed halls of the Tecnológico de Monterrey, transcends the confines of specific academic institutions. Its universal applicability extends to chemistry courses spanning all academic echelons and, indeed, even to those individuals whose pursuits lie beyond the conventional realms of academia.

The city analogy serves as a resource for understanding electron configuration. It makes it easier for us to see it and understand it. As they walk the streets of this imaginary city and enter the houses, each with its layout of rooms, students embark on a journey of discovery and learning about how electrons are organized within an atom. Some students shared that the city analogy strategy helped them understand the concept of electron configuration in a way that traditional methods could not. This educational strategy facilitates the teaching of electron configuration and explains its basic principles in a clear and simple manner.

The city analogy strategy is not only academically useful, but it also transcends disciplinary boundaries and can capture the imagination of anyone interested in the subject. It's important to note, however, that while the strategy has proven effective for many, it may not work for everyone. Some students may find it too simplistic or prefer more traditional teaching methods. The city analogy is a testament to the transformative power of innovative pedagogy.

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# IoT for experimentation in control systems education

José M. Ramírez-Scarpetta[1], Julio E. Urbano[1], Esteban E. Rosero[1], Fabio Guerrero[1]

[1] School of Electrical and Electronic Engineering, University of Valley, Cali, Colombia

Email: jose.ramirez@correounivalle.edu.co, julio.urbano@correounivalle.edu.co, esteban.rosero@correounivalle.edu.co, fabio.guerrero@correounivalle.edu.co

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**Abstract**

Engineering education and control systems education face the challenge of updating their curricular elements to adapt to the new needs of industry and society. New technical and transversal competencies, related to technological change, such as the use of digital tools like the Internet of Things IoT, and computer knowledge, are reported as required in the industry. The work presents tools for experimentation in control systems, using cloud computing, IoT, digital communications, and data analysis. Any student with Internet connectivity, programs the controllers in the cloud, anytime, anywhere; using inexpensive rapid prototyping systems such as Raspberry Pi, and low-cost IoT devices, they perform experiments on real systems such as air temperature, soil humidity, and the level of a water tank. Experiences of using these technologies are presented in an interdisciplinary control course, and the first engineering project course, from the electronic engineering program of the Universidad del Valle. Both courses use Project Based Learning, enhanced using these new technologies.

Keywords: Engineering Education; Internet of Things, Control Systems, Digital Communications.

## 1 Introduction

Technological change has generated a gap between industry and academia (Besová & Tupa, 2007). Multiple works have reported the integration of new technologies such as Artificial Intelligence, Cloud Computing, Internet of Things (IoT), and Data Analysis, in the industry (Xu, Xu & Li, 2018). The industry now requires engineers with specific competencies such as knowledge and use of the aforementioned technologies, and transversal competencies such as computational literacy, problem-solving, teamwork, and others (Kumar & Ekren, 2020).

The focus of Convergent Technologies and Industries 4.0 of the Wise Mission (Minciencias, 2020), from the description of Critical Architecture for Innovation and Global Opportunity, proposes in the Foundational Layer, elements such as cloud computing, affordable high-speed communication, and cybersecurity; in the Value Layer, IoT, data analysis, robotics, and sensors. Additionally, this Mission in the focus of Social Sciences and Human Development with Equity proposes as the first strategic axis of intervention, the reduction of educational gaps and those that affect access to science and technology, to contribute to sociocultural equity, and economic growth. The different types of technologies of Industry 4.0 are from various disciplines, so there is the need to have learning environments where they can be integrated, with their respective support resources, and with active learning methodologies that facilitate the development of transversal skills for their use, design, and technological programming, (Universia, 2024).

This paper presents support resources for learning activities in two engineering courses. The first course is an integrative project course in the sixth semester of the electronic engineering program; the course integrates project management tools with the disciplines of control systems and communications. It uses as an experimentation tool a digital control system with a radio frequency communication network. The second is an elective course interdisciplinary, offered to electrical, mechanical, chemical, and electronic engineering. It uses an IoT experimentation platform, which allows Ethernet networked control systems and the controller in the cloud.

The rest of this document is structured as follows: section 2 presents the courses of Engineering Projects, System Controls, and Communications. Section 3 shows the different schemes of the experimental prototypes for integrated control and communication experimentation. Some experimental results and students' opinions about the resources are presented in section 4. Finally, section 5 presents conclusions and future work.

# 2 Projects, controls, and communications courses

IoT enables the interconnectivity of devices and systems, collecting and sharing data. Modern engineers must face increasingly complex, interconnected systems, applied in multiple fields of knowledge. Therefore, education in control systems and communications must provide a solid theoretical base, exploiting these new technologies. Furthermore, solutions to problems in engineering are normally carried out through projects, so it is also important to develop the transversal skills required for these projects. In response to these challenges in 2018 the Faculty of Engineering of the Universidad del Valle carried out a curricular reform of its 18 undergraduate programs (González, 2019). The curricular redesign established, for all the faculty's programs, engineering project courses in the upper semesters, to integrate the transversal skills and the necessary knowledge of various disciplines, to develop engineering projects, in disciplinary or interdisciplinary teams, that seek to solve problems in the engineering context.

Figure 1 shows the integration of projects, control, and communications courses for the electronics engineering program.

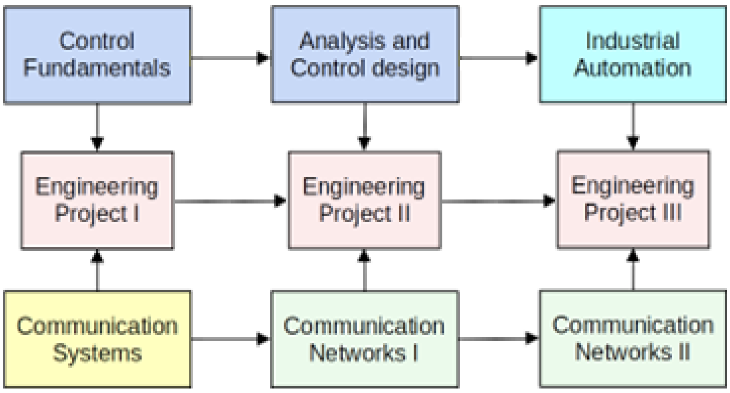


Figure 1. Project, control, and communications curricular components.

## 2.1 Engineering project courses

The engineering project courses are between the sixth and eighth semesters and have around 15 students. The courses are developed around integrative projects whose milestone is the analysis of a contextual problem and the conception and execution of a project that allows its solution, integrating different concepts of electronic engineering. Throughout these courses, financial analysis tools and project management skills are addressed, and the transversal competencies: Capacity to develop engineering projects, teamwork, and communication skills, engineering problem-solving skills, critical, creative and systemic thinking. Teams of three students address the different phases of the project, where they define the problem and design a solution, which is implemented in an emulation prototype. Experimental practical training is carried out with the activities demanded in the project. Evaluation activities are training reports, written reports, and oral presentations to the entire group about the progress of each project.

The first engineering project course has learning outcomes to perform the conceptual analysis and basic engineering, as well as design and implement a PID control system, with a wireless communication network. In the Engineering Project II course, students perform detailed engineering for more complex systems that require other controllers like RST and state feedback, use electronic instrumentation for measurement, and communication networks with Ethernet. The third course integrates disciplines of high-level industrial automation, wide area networks, artificial intelligence, and environmental impacts of solutions.

To learn project skills in the Engineering Project I course, master classes, role plays, and training in software tools for project management are carried out. The course integrates the control and communication disciplines, through contextualized projects, whose solutions are implemented in a laboratory prototype. For example, the Irrigation Tank Project raises the problem: '*A sugar factory has an automatic irrigation system for a sugar cane growing area in the Cauca Valley, located in the foothills of the central mountain range. To feed this irrigation system, the sugar factory has a vertical cylindrical water tank with a 4m radius and one million liters of capacity, located 500m away and on a base 10m higher than the crop. The factory requires that a smart agriculture company with IoT (students) provide a system that prevents water spills in the tank and guarantees constant pressure to the irrigation system. The regional environmental authority CVC ensures that the communities and companies that use and exploit the water from the tributary to the tank, use it properly under the permits granted*.' The project is emulated in the Automatica Laboratory, using the PCT-M Water Tank Prototype, which has a tank, and a pump to change the inlet water flow and tank discharge pipes. In this course the initiation and planning phases of the project are addressed, defining the problem and performing the basic engineering to design a solution, which is implemented in the emulation prototype, using the experimental integrator resource for communication and control presented in the section 3. Experimental practical training is carried out with the activities demanded in the project, in another prototype for the speed control of a motor.

## 2.2 Control systems courses

Control systems in the IoT framework facilitate remote monitoring and control and improve performance through data analysis. The implementation of control laws could be digitally in micro-processed embedded systems or directly in cloud computing. Likewise, the high availability of online data requires data engineering to obtain discrete dynamic models and tune digital controllers.

In the two control courses, students can model, analyze, and design invariant, continuous, or discrete linear control systems with input-output and state space representation, in the temporal and frequency domain. In the control fundamentals course, students are expected to be able to: define the control system problem, model, and analyze feedback dynamic systems, and analyze PID control actions. In the analysis and control design course, students are expected to be able to: analyze the stability, the root locus, and the frequency response, and design PID, RST, state feedback controllers, and other control architectures. Control systems require high mathematical abstraction, with the use of mathematical concepts and tools for modeling, analysis, and design of dynamic systems. In the control courses, theoretical concepts are introduced through gamification, with animated games on the computer. The mathematical modeling, analysis, and design are carried out in computer rooms with the MATLAB® software (Matlab, 2024a), structured in computer books with live scripts (Matlab, 2024b). The application of the theory is carried out in theoretical-practical sessions in which portable and virtual laboratories are used in the classroom to bring the student closer to the theoretical concepts and the reality of the behavior of control systems.

The Interdisciplinary Control course is an elective offered to electrical, electronic, mechanical, and chemical engineering programs. In this course, data management techniques, data modeling, and design of discrete controllers are introduced, which allow for achieving maximum productivity and profit, and minimum energy consumption, in industrial and IoT environments. At the end of the course, is expected that the students will be able to define the characteristics and specifications for a control problem based on data; manage data for collection, processing, analysis, and display; model dynamic systems in discrete time from data; design PID, RST, state feedback and predictive control laws based on models, to obtain the desired performance for the controlled system; integrate plant, measurement, actuation and communication with the discrete controller, to implement the designed control in an industrial and IoT environment. Students were organized into teams of three students, two of them from different disciplines. The projects were open to choose by the teams, which chose: The purification of water through a chlorine dosing plant, with industrial IoT; humidity control for a crop in the context of smart agriculture with IoT; level control of a water tank for a rural home, with IoT; and temperature control in a pipe through which a sugar solution flows, in the context of industrial IoT.

### 2.3 Communication courses

As shown in Figure 1, the communications curricular component is based on three theoretical courses: Communication Systems, Communication Networks I, and Communication Networks II. Although these courses are, in principle, theoretical in these days of great technological advances and digital competency, these courses are taught using a variety of tools such as simulators, mathematical animations, demonstrations in class using physical equipment such as routers, and so on. These courses at the same time contribute to the Engineering Project sequence (Figure 1). Learning activities for Engineering Project I include the programming and deployment of wireless devices mainly in point-to-point topologies. Learning activities for Engineering Project II include the programming of a simple LAN network applying concepts such as IP addressing, DHCP server, Gateway, VLAN, etc. Learning activities for Engineering Project III from the communications component include programming and implementation of WAN networks applying concepts such as inter-domain (e.g. BGP) and intra-domain (e.g., OSPF) routing protocols, MPLS, VRF, QoS, and so on.

The Communication Systems course is about the theory of the physical transmission of signals, a highly mathematical issue that addresses signals and transmission media in communication systems, communications link budget, random communication signals, reliable transmission of information, continuous wave modulation, and digital modulation. The first Communication Networks courses cover the classical content through the different layers of OSI, TCP/IP, and NGN communication network models that make the provision of services and applications through a data network, with the most visible example of this field of knowledge being the Internet. Communication Networks I encompass communication networks models, physical layer, and data link layer with all its underlying details. Communication Networks II encompasses the Network Layer, Transport Layer, Transport Layer Security, and Application Layer, it includes Network protocols in the context of LAN, MAN, and WAN networks; inter-domain and intra-domain routing protocols using distance vector, link state, and path vector (BGP) algorithms; medium-sized communication networks focused on solving data communication needs in corporate environments; and transport layer protocols, DHCP and DNS.

## 3 Experimental resources

Figure 2 shows the schema for integrated control and communication experimentation. The schema proposes different approaches to connect the controller and the process. Both the controller and the process can be deployed either locally or online where the process can be physical laboratory equipment or a virtual application.

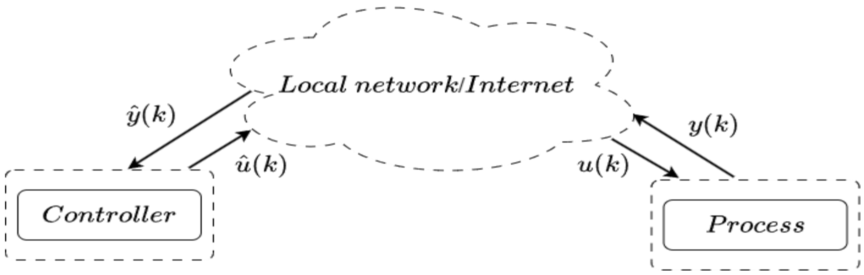


Figure 2. General schema.

Table 1 summarises the different configurations proposed in the schema of Figure 2. The case where the controller is deployed locally and the nature of the process is physical corresponds to the traditional configuration of a laboratory at universities where practicing activities are performed using data acquisition boards and students have direct access to the laboratory equipment.

Table 1. Configurations of experimentation resources depend on the nature of the process, the type of connection between the process and the controller, and where the controller is deployed.

| Controller | Nature of the process | | Type of connection | |
|---|---|---|---|---|
| | Physical | Virtual | Local | Internet |
| Local | X | | X | |
| | | X | X | |
| | | X | | X |
| Online | X | | | X |
| | | X | | X |

With the controller placed locally and the process online, the numerical dynamics of the process, which can be a tank-level, a thermic system, or any other, is deployed on the internet as an application. The application receives an input signal and generates an output signal that is sent back to the controller. The controller is implemented locally in MATLAB Simulink. Both elements communicate with each other using the TCP/IP protocol. MATLAB Simulink is equipped with TCP/IP connection blocks which makes it easy to configure and deploy control loops with multiple types of control algorithms like Proportional-Integral-Derivative and State Feedback. Table 1 also shows that with a local controller and a virtual process, the type of connection can be local. In the latter case, the application of the virtual process is hosted on a platform such as Raspberry Pi.

The connection mechanism implemented in the schema of Figure 2 introduces non-deterministic communication delays. The schema of Figure 2 assumes a sampling time that should be synchronized in both elements, controller, and process. The sampling time is selected according to the temporal response of the process and the performance requirements in a closed loop; also, communication latency must be considered to decrease the effect of connection delays.

For quasi-real-time execution on MATLAB Simulink, a sample time of 300 ms has been found as appropriate to synchronize controller computations and TCP/IP communications, the latter with communications through the internet. Working on a local wired network connection, communications, and controller computations can be synchronized with a sample time of 50 ms.

For local connections, a wired or wireless network can be used. Wired connections have been found more stable than wireless ones where data between consecutive samples can be lost. Wi-Fi and Radio Frequency RF communication technologies have been proposed to deploy the wireless approach. Using Wi-Fi, by the side of the controller, an application implementing a control algorithm capable of receiving the error signal and calculating the control signal; MATLAB Simulink along with the MyDAQ data acquisition board, and TCP/IP connection blocks, are used to acquire and generate the process and reference signals to finally calculate the error and send it to the controller.

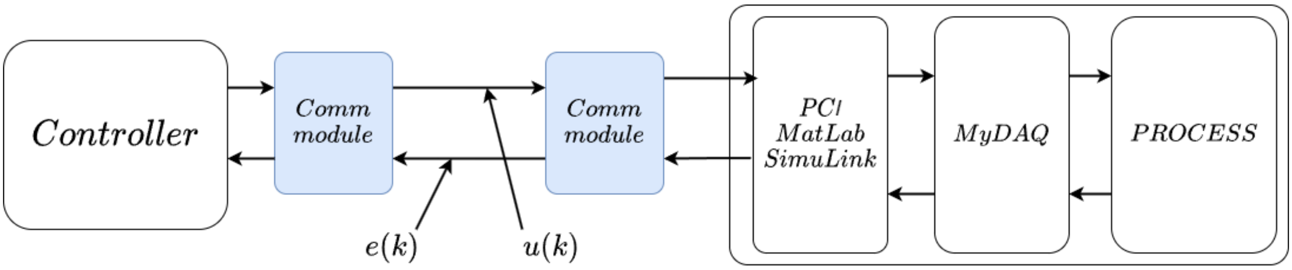


Figure 3. Control loop using RF communication.

The use of RF communication requires extra hardware on both elements of the schema since RF devices cannot be connected directly to the computers. Figure 3 presents the elements disposed to use RF to communicate the process and the controller. The communication module of Figure 3 corresponds to an RF device of reference nRF24L01 plus a USB serial adapter. The USB adapter interfaces the RF device to a serial port which can be directly accessed from MATLAB Simulink.

To access the controller or the process deployed on the internet, public IP addresses of the applications running online should be available. There exist multiple services which provide solutions to deploy such applications. Additionally, tools like Ngrok (ngrok, 2024) allow to deployment of these applications online with no need for the cloud. Activities performed in control systems courses used Ngrok to deploy processes online and create cloud-based control loops to test control algorithms and do identification exercises.

The Interdisciplinary Control course used the scheme in Figure 2 with a local Raspberry Pi to emulate the process model, a local PC or in the cloud, was used for the controller. In the Engineering Project I course, the scheme in Figure 3 is used.

# 4 Results

This section presents some experimental results and students' opinions about the resources described in the last section.

## 4.1 Experimental results

Figure 4 shows the input-output response of a process deployed virtually through the internet. For this response, the configuration of the resources corresponds to a controller deployed locally on MATLAB Simulink, and the process is deployed virtually using a Raspberry Pi board, and communication through the internet with the tool Ngrok. In Figure 4 the control system is in an open loop and the controller is reduced to a unitary gain. As can be seen in Figure 4, the response features communication delays which are visible with input changes.

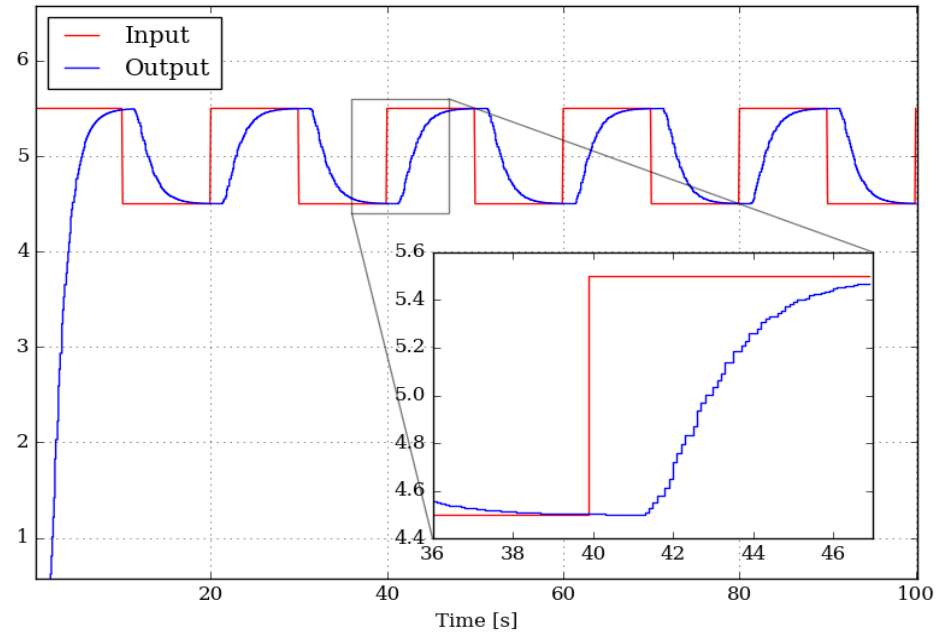


Figure 4. Input-output response. Process deployed virtually through the internet.

In Figure 5, the input-output response corresponds to a temperature control with a RST controller deployed in the cloud and the process is a pipe through which a sugar solution flows, deployed virtually in a Raspberry Pi board. Good performance is observed in tracking the reference and rejecting the disturbance between 40 and 60 s.

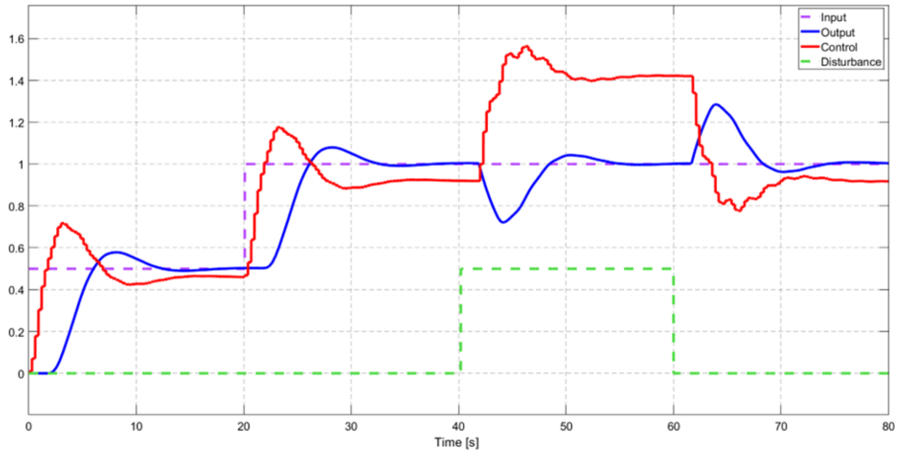


Figure 5. Input-output response. Process deployed virtually through the internet.

In Figure 6, the input-output response corresponds to a local controller connected to physical laboratory equipment using RF communication. In this configuration, the physical system used was a direct current motor and the signal sensed was the angular speed interfaced to the data acquisition board using a tachometer which finally provides a voltage signal.

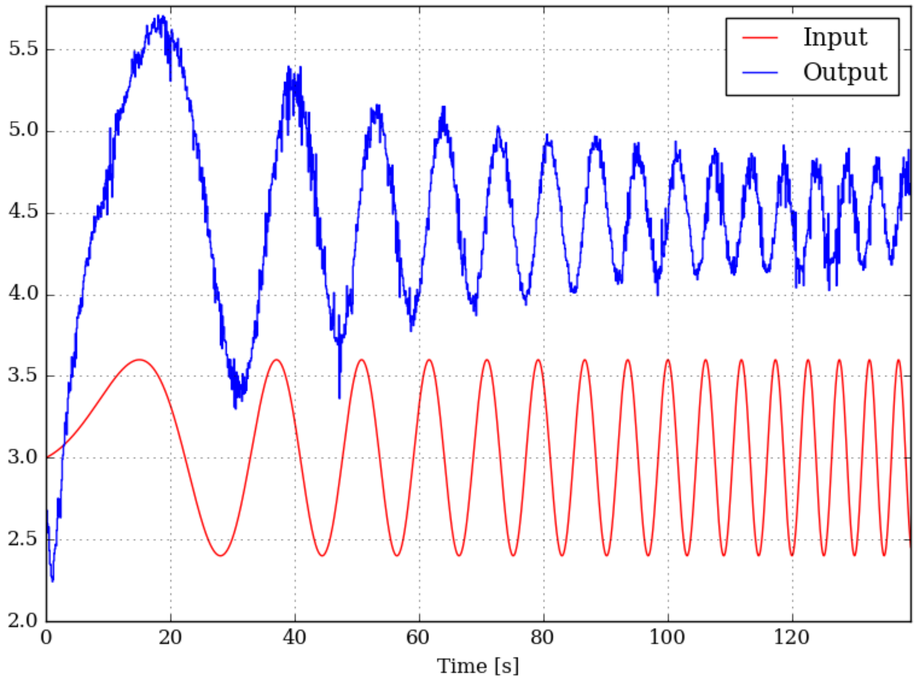


Figure 6. Input-output response. Local controller and physical process using RF communication.

## 4.2 Interdisciplinary course

The advanced control systems course was taught in the first semester of 2023, for 10 students, of which five were from the electronic engineering program, four students from the electrical engineering program, and one mechanical engineering student. Students evaluated the course anonymously. Some of the questions related to practical experimentation are shown in Table 1.

Table 2. Questions.

| # | Questions |
|---|---|
| 1 | The course was relevant to my training. |
| 2 | The practice allowed me to develop skills for professional performance. |
| 3 | The theoretical knowledge acquired was consistent with the practice I developed. |

The questions in Table 2 are rating questions with a range from zero to five, where zero corresponds to the lowest rating and five to the highest. For the questions in Table I, the students' evaluation of practical experimentation was 5.0/5.0. The overall course average was 4.47/5.0.

With these results it can be concluded that practical experimentation has been well accepted by students, highlighting that it is easy to use, integrates different physical elements and different types of signals in a control loop, of great support for learning control systems. Some observations from the students were that the interdisciplinary course helped them carry out practical experiments based on the theoretical concepts of control systems.

## 4.3 Project course

At the time of writing, the course is 50% complete; the teachers of the three courses participate in its development. So far, student participation has been very active and purposeful; The evaluation of the first phase of the projects had an average grade of NN. Full results are expected to be reported in a future publication.

# 5 Conclusions

IoT includes various technologies such as Cloud Computing, Data Analytics, Virtual Reality, and Communications. Engineering education has the challenge of integrating these technologies into its teaching-learning processes, also providing new transversal skills such as problem-solving, systemic analysis, and computational thinking. This work has presented experimental resources in the context of IoT. They allow local real/virtual processes, and local/cloud controllers, interconnected through RF networks or the internet. This allows students to connect to the experimental resource anytime, anywhere. The results of having used these resources in the interdisciplinary course, show good experimental behaviors, relevance in the formation of control systems, and high acceptance by students. The use of these experimental resources in engineering project courses is just beginning, but they already show the advantages of using the IoT as an integrative experimental resource.

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# Ecological Engineering Integration: A PBL Journey Towards Sustainability in Rural Project Contexts

Juliana Zuluaga-Carrero[123], Fernando José Rodríguez-Mesa[1,2]

[1] Programa Especial de Movilidad Académica Peama-Sumapaz, Universidad Nacional de Colombia
[2] Universidad Nacional de Colombia, Bogotá
[3]Línea de Investigación en Conectividad e Interacciones Ecológicas, Jardín Botánico de Bogotá José Celestino Mutis

Email: juzuluagac@unal.edu.co, fjrodriguezm@unal.edu.co

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**Abstract**

Amid the current challenges posed by climate change and human-induced environmental shifts, rural higher education plays a crucial role, serving as a dynamic platform to address diverse issues across various disciplines. Although education in rural areas is uneven, leading to significant gaps in the learning process and differences in educational content, it is a platform to introduce sustainability approaches. To address rural education, the Universidad Nacional de Colombia has a Special Admission Program using Problem-Based Learning (PBL). This four-term program aims to enhance both soft and hard skills through transversal projects. Being rural implies ecology as a central theme in several disciplines. Ecology prompts students to reflect deeply on their communities. PBL projects encourage students to explore multidisciplinary connections, seeking alternative solutions for their communities. Within this framework, ecology provides an excellent opportunity to examine different dimensions—economic, social, and environmental issues. The process begins by constructing a problem tree that encapsulates these challenges. Various tools, such as field trips and basic descriptive analyses of real situations, are then employed for in-depth study. Between 2022 and 2023, a total of 20 student projects were implemented. In the initial semester, students adopted an observational approach to familiarise themselves with their territories and refine their problem trees. Subsequent terms empowered students to conduct experiments within their communities, aiming to explore and address significant issues from a sustainable perspective grounded in an interdisciplinary. Among these projects, 15 utilised socio-ecological systems and maps, while three explored various strategies to enhance their understanding of sustainability through experiments and tools such as biodiversity catalogues and surveys in rural communities. This approach illustrates how engineering students can deepen their comprehension of their territories, acting as a guiding tool for their learning process and reflection on different problems within the special program, providing valuable tools for future academic projects.

**Keywords**: Project-Based Learning, Ecology, Sustainability Engineering, Rural Education

## 1 Introduction

Globally, young students typically demonstrate average proficiency levels in problem-solving abilities and numerical tasks. However, in Colombia, these skills exhibit significant disparities primarily driven by socioeconomic inequalities (OECD, 2022). Educational programs around the world face challenges in meeting the demand for graduates who possess the necessary knowledge and skills to tackle complex ecological issues in an ever-changing global landscape (Jalkanen et al., 2020; Lewinsohn et al., 2006). Students globally face challenges in integrating knowledge and addressing societal issues due to difficulty in memorization. Educators must prioritize critical thinking to cultivate future professionals capable of tackling global challenges. Sharing expert methods and encouraging practical skill development can deepen understanding of ecological processes (Nordlund, 2016). This prepares students for real-world application and interdisciplinary collaboration amidst unsustainable human practices and the urgent need for sustainability education outlined by the United Nations' Sustainable Development Goals (Klemow et al., 2024).

The learning process in universities encompasses two main components. Firstly, there's the aspect where students are actively involved in learning, which involves cognitive processes and individual functions. Secondly, instructors play a crucial role in engaging with students during the learning process, potentially enhancing student learning outcomes. Various theories and research on learning highlight factors within classrooms that affect learning and teaching. These include principles such as Research-Based Smart Teaching, consideration of students' prior knowledge, understanding of how knowledge is structured, motivation, development of mastery skills, and integration of social, emotional, and intellectual interactions. Furthermore, the importance of students becoming self-directed learners, capable of regulating their own learning, is emphasized (Ambrose et al., 2010).

Active learning has been promoted as a method to bridge gaps in outcomes in STEAM disciplines, including ecology (Lewinsohn et al., 2006). Despite a strong reliance on lectures, there has been an increase in its use by instructors in recent years (Eagan et al., 2013). Receiving institutional backing for active learning methods is vital. The absence of administrative support becomes apparent in students feeling constrained due to insufficient physical learning environments and limited faculty training in active learning approaches (Foote, 2016). Achieving institutional commitment is a recognized challenge that requires adequate acknowledgment by academic institutions, which promotes the search for innovative teaching methods (Barr & Tagg, 1995; Cavanagh, 2016). Choosing an appropriate strategy can be facilitated by instructors exploring new teaching methods in ecological classrooms. This includes the promotion of active learning for STEAM instruction, such as problem-based learning, and providing comprehensive methodological overviews with practical implementation advice (Lewinsohn et al., 2015). Early career teachers encounter insufficient support for professional development, despite the pressing demands of time. However, collaborating with experienced colleagues proves invaluable in navigating these challenges (Gaulke et al., 2024).

Problem-Based learning emphasizes student-centered active learning through problem-solving activities driven by the quest for solutions (Savin-Banden & Howell, 2004). Relevant, realistic problems with inherent complexity enable students to explore various pathways and multiple valid solutions. Additionally, analysing solutions requires prior collaboration among students facilitated by an instructor (Balzano & Marzi, 2023; Barrows, 1980). Solutions may be multidisciplinary with different tools, enhancing students' soft skills and specific knowledge areas, teamwork, leadership, and social interaction fostering meaningful learning beyond the classroom (Brundiers & Arnim, 2013; Williams et al., 2010).

Theoretical underpinnings for problem-based learning stem from social constructivism, social development, and social interaction, where knowledge is formed through collaborative interaction tailored to the context (Savin-Banden & Howell, 2004; Vygotskiī, 1978). The instructor's primary role is to facilitate learning by presenting meaningful problems and offering support as needed. Effective learning occurs when individuals are challenged with concepts slightly above their current level and are provided with the necessary assistance to grasp them. Cooperative learning theory further supports this approach by advocating for problem-based group work, which not only enhances achievement but also fosters critical thinking skills and promotes active engagement among (D´Avanzo, 2003). Evidence suggests significant gains in applied and process skills, student engagement, and applied knowledge assessment compared to traditional classrooms. It's essential for instructors to develop skills to effectively facilitate active learning, including problem-based learning (Gijbels et al., 2005).

The educational approach at Roskilde University, established in 1972, is characterized by interdisciplinary problem-oriented participant-directed project work, which has drawn attention from institutions across Europe. Known as Problem-Oriented Project Learning (OPPL), this framework emphasizes group work, the exemplary principle, and social relevance to create a dynamic learning environment. Through real-world problem-solving, students tackle scientific and social issues, prioritizing hands-on approaches over traditional assignments. Interdisciplinary collaboration allows flexibility in choosing theories and methods, enriching learning experiences, while the exemplary principle encourages students to explore specific problems for broader insights. Within this structured curriculum, participant-directed learning and group work are pivotal for fostering collaboration and peer learning (Andersen & Heilesen, 2015a).

Derived from the theory that underpins Problem-Based Learning (PBL), PEAMA Sumapaz has designed its own model focused on rural and transdisciplinary education, which is called the Torca Model (Rodriguez-Mesa, 2022). The Torca model incorporates students from various programs who work together within the same framework, supported by two facilitators and teachers from the different subjects involved in the project. Each teacher enriches the students' perspectives, helping them to achieve the learning outcomes for each respective subject (Rodriguez-Mesa, 2023; Rodríguez-Mesa et al., 2023). One of the experiences includes pedagogical field trips focused on the recognition of the territory in some of the subjects and problems in the project-work.

# 2 Methods

This study will focus on presentations detailing a process undertaken between 2022 and 2023, showcasing projects designed by students. The objective is to illustrate how students formulate objectives rooted in ecological principles to address real community issues using engineering solutions. These discussions will draw from experiences in rural areas such as Sumapaz, Nazareth, Ciudad Bolívar, and Torca—rural communities around Bogotá, Colombia. In these areas, the Universidad Nacional de Colombia has enrolled new students in different academic programs for the first four semesters.

## 2.1 Area of study

The PEAMA Sumapaz program (PSP) began at the National University (Acuerdo 025, 2007) is a program aimed at students from rural areas. In 2016, in collaboration with the District Secretary of Education, the program was expanded to include graduates from all rural schools of Bogotá, creating the PSP (Resolución 405, 2016). This program focuses on improving reading, writing, and mathematics skills. This program uses the approach of PBL, in which they can improve as well as other fundamental subjects and soft skills that provide students with tools to elevate their academic level. Given the significant education disparities in rural areas, students from these regions are at a higher risk of dropping out. Therefore, the program serves as a framework to help reduce dropout rates. In Colombia, the dropout rates in higher education are alarmingly high, with nearly 12.84% of students affected (MEN, 2023) highlighting a significant challenge for education in rural areas. Program students complete the first four semesters of various degree programs, including Engineering, before transitioning to urban campuses in Bogotá to complete their studies.

The intention is for them to undertake their final projects in their home regions, addressing local challenges and contributing to regional development. It is important to note that the PSP campus is situated within the territory belonging to Locality 20 of Bogotá, which is part of the rural area of the capital of Colombia. In this context the discipline of ecology brings to students the opportunity to explore dimensions that compound their territory as environmental, economic and social aspects, which is an excellent platform for improving their academic abilities at the same time to know better their homes.

## 2.2 Project's structure

In the four semesters of the PSP, students undertake one project per semester within interdisciplinary groups comprising students from various fields. The initial two semesters focus on acquainting students with the region, exploring its key areas, some of which have been home to families for generations, fostering collaborative knowledge creation. This approach enables students to delve deeper into significant community issues. In the subsequent two semesters, students develop experimental designs, collect data on real-world challenges, and propose potential solutions, often in collaboration with community members, friends, and relatives. The projects cover diverse problems, topics, and disciplines, allowing students to progressively enhance their understanding of the region and its environment, thereby evolving their project approach over time (Figure 2).

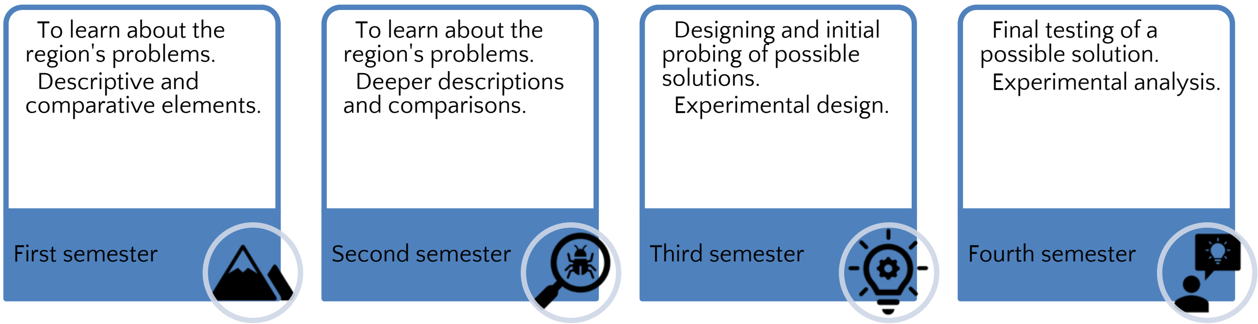


Figure 1. Project structure in PSP.

The project provides a structured framework for guiding students in interdisciplinary group work, featuring a written document and two oral presentations: one for the teaching staff and another for the community. The manuscript includes sections like context, problem statement, justification, research question, objectives, methodology, conceptual framework, results, and references. Students are encouraged to develop their conceptual framework early in the project, utilizing social, economic, and environmental research tools for information. They also utilize problem and solution trees to comprehensively understand and identify the problem.

It is important to note that in the latter semesters (third and fourth), students incorporate an additional component: a discussion of their results in the light of theory. At the end of each semester, students from all semesters are required to make presentations. These presentations are delivered to both professors and students and include a session for questions and answers. Furthermore, selected topics are presented to the community as part of an organized event in which community members can know more about the results and propose possible initial solutions.

## 2.3 Case study

In each subject within the program, teachers must align with the intended learning outcomes (ILOs) specified in the university's faculty syllabus. For instance, in the case of ecology, which falls under the Science Faculty and Biology Department, instructors select relevant topics from the syllabus that are applicable to the project's challenges. Ecology covers a range of essential topics, providing students with a comprehensive understanding of various issues. By adopting an approach that spans different scales, students explore knowledge related to their region. This exploration begins at the global level and progresses through regional, local, species, and organism levels. The ecological approach encompasses biogeochemical cycles, the flow of matter, ecosystem characteristics, and habitat features. Additionally, it considers the living environment of human communities and its connection to specific energy flux cases arising from their projects. Some of these cases involve describing energy flow in trophic webs and food chains, while others focus on interactions between species. These insights allow students and the community to better understand their environment and the fundamental structure and organization of life.

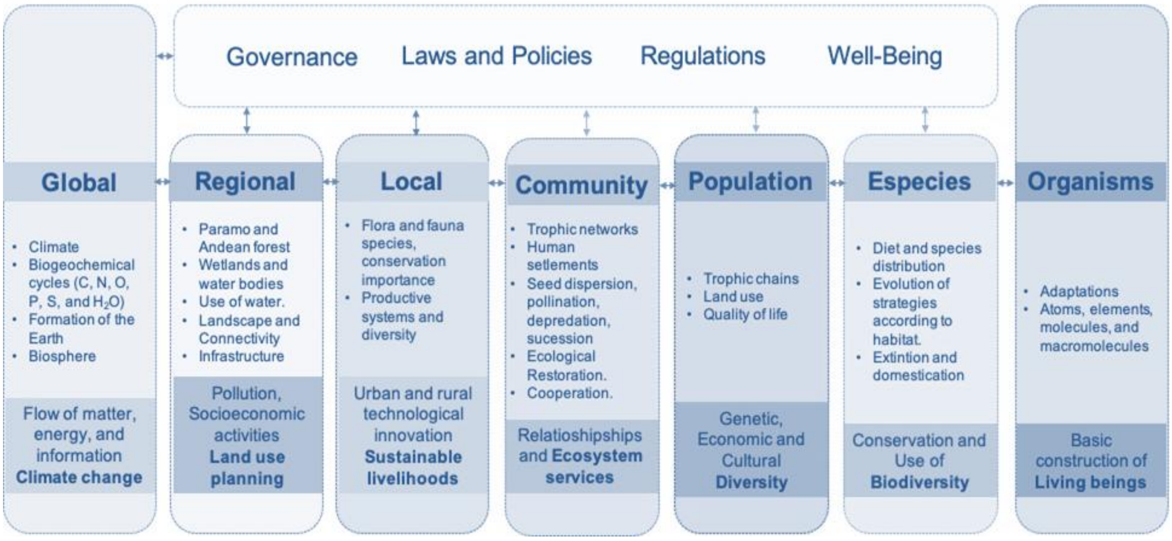


Figure 2. Ecological Perspective in Engineering Education.

# 3 Results

During the period spanning 2022 to 2024, students from various academic programs undertook different projects that took ecology as a transversal subject in the first semester. There are different careers in this sample, encompassing disciplines such as electrical engineering, mechanical engineering, electric engineering, mechatronic engineering, and agronomic engineering. Is important to mention that these projects involved collaboration with varied fields including social work, biology, business management, architecture, and anthropology.

## 3.1 Types of projects

During this period, a total of 20 projects involving 115 students were completed, yielding various outcomes. The analysis of these projects utilized categories of green technologies, recognizing their crucial role in achieving global and local development goals. These goals aim to mitigate negative consequences and promote environmental sustainability by integrating solutions that consider the environment, economy, and society (Guo et al., 2020). Within these categories, key issues pertaining to sustainable engineering were identified, including Education, Environmental Management and Conservation, Mobility and Transportation, Water, Loss of Traditional Knowledge, and Education.

**Table 1.** Problems and dimensions of the ecological perspective, the number of students and projects 2022-2023.

| | |
|---|---|
| **⊟ Education** | **20** |
| Social | 10 |
| Social, environmental | 10 |
| **⊟ Environmental Management and Conservation** | **58** |
| Social, environmental | 7 |
| Social, environmental, economical | 21 |
| Social, environmental, technological | 12 |
| Social, environmental, technological, economical | 18 |
| **⊟ Loss of Traditional Knowledge** | **7** |
| Social, environmental, technological | 7 |
| **⊟ Mobility and Transportation** | **3** |
| Social, economical, technological | 3 |
| **⊟ Territorial Planning** | **3** |
| Social, environmental | 3 |
| **⊟ Water** | **14** |
| Social, environmental, economical | 3 |
| Social, environmental, technological | 5 |
| Social, environmental, technological, economical | 6 |
| **Total general** | **105** |

## 3.2 Rubric of evaluation

The evaluation rubric is grounded in an outcomes-based approach, emphasizing what each student will know and be able to do upon completing a course. These approaches align with teaching and learning activities outlined in the department's syllabus. Importantly, the evaluation process is based on the SOLO taxonomy (Biggs et al., 1982). SOLO (Structure of Observed Learning Outcomes) provides educators with a systematic method for designing curriculum, formulating learning objectives, and assessing student performance. Within this taxonomy, six key cognitive levels are identified: 1) knowledge, 2) comprehension, 3) application of knowledge, 4) analysis, 5) synthesis and 6) critical thinking. The rubric also incorporates elements from other authors, such as the assessment of intended learning outcomes (ILOs) which draw from Bloom's Taxonomy at various levels. Learning in this domain involves adaptation and reorganization, potentially leading to both specific and generalized experiences, and is assessed through the application, selection, and treatment of problems (Andersen & Heilesen, 2015b).

## 3.3 PBL in groups skills

During ecological activities, student groups exhibit diverse dynamics while utilizing tools such as cartography and community surveys. Seminars in ecology serve as platforms for presenting theoretical frameworks relevant to projects, involving a thorough review of pertinent literature. Subsequently, students delve into practical tasks, designing optimal methods for gathering information from their respective territories. Collaborating within groups, they engage in discussions and reach agreements to achieve desired outcomes. Furthermore, workshops explore the functioning of different habitats within communities. Some workshops specifically focus on sustainability elements across economic, social, and ecological domains. The overarching goal is to construct meaningful relationships between these domains in the context of the chosen problem.

## 3.4 Challenges

There are various challenges associated with this method. One of the most significant challenges is ensuring that students effectively collaborate in groups. Although students may reach agreements to achieve outcomes, it is crucial to ensure that they adhere to these agreements and make progress toward their goals. At times, students may struggle to organize tasks and meet deadlines for project submissions. In such cases, it is important to provide support through collaboration with other professionals, psychological support, and facilitators to assist with their activities. Additionally, a chancellor can play a crucial role in connecting with the community.

# 4 Discussion

The objective of this study is to illustrate how students formulate objectives rooted in ecological principles to address real community issues using engineering solutions. In this case study based on problem-based learning (PBL), several key findings emerge. First, the interplay between ecology and engineering plays a crucial role in fostering sustainability initiatives that address environmental challenges. Second, the methodology increases awareness of environmental problems. Third, the evaluation rubric emphasizes that students will acquire knowledge and skills by completing the course syllabus. Additionally, PBL contributes to the development of group skills, as students engage in discussions, reach agreements, and achieve desired outcomes. However, students also encounter difficulties when analysing community problems and striving to meet the defined objectives.

The integration of ecological principles and engineering practices within project-based learning (PBL) holds promise for advancing sustainability initiatives. Our research findings align with (Lavado-Anguera et al., 2024), who emphasize the critical need for interdisciplinary collaboration. By bridging ecological understanding and engineering solutions, students gain a holistic perspective on environmental challenges. However, further research is warranted to explore specific strategies for optimizing this interplay. While environmental management and conservation receive significant attention, other areas such as territorial planning and mobility remain less explored. Notably, the process of social learning within sustainable development can effectively inform projects implemented by both the public and private sectors, connecting teaching and research with real-world needs and problems (Cazorla-Montero et al., 2019). Over time, students may identify additional real-world challenges based on their knowledge of the local context and interactions with people.

Project-based learning (PBL) effectively heightens students' awareness of environmental issues. Through engagement in real-world projects, students grapple with complex problems, deepening their understanding of ecological dynamics. Future studies should explore the long-term impact of this heightened awareness on students' environmental consciousness. Notably, this study highlights specific PBL projects that introduce students to real-world ecological problems. The research findings align with the New Ecological Paradigm (NEP) scale, emphasizing interdisciplinary collaboration and engagement. In a rural context, possible alternatives are proposed, emphasizing the importance of working with other disciplines for enriching discussions about the problem and potential solutions (Nanni & Allan, 2020). Through active engagement in real-world projects, project-based learning (PBL) offers opportunities to tackle complex environmental challenges and connect sustainability knowledge with positive environmental behaviours (Bramwell-Lalor et al., 2020).

Collaborative learning lies at the heart of project-based learning (PBL). Lavado-Anguera et al. (2024) emphasize the significance of negotiation, teamwork, and effective communication during PBL. Students actively participate in discussions, reach consensus, and collectively strive toward desired outcomes. To optimize group dynamics, educators can explore strategies for managing conflicts, fostering inclusivity, and promoting collaboration within project teams. Organizing work based on prior agreements becomes crucial to ensure alignment with goals. As students gain experience, their understanding of teamwork evolves, leading to more refined agreements over time.

PBL goes beyond rote memorization, allowing students to develop research skills. Our findings align with emphasizing the application and comprehension of ecological concepts. Encouraging students to explore real-world data, conduct fieldwork, and engage in inquiry-based learning can further enhance their research capabilities (Almulla, 2020). Despite the benefits, students encounter difficulties when analysing community problems and meeting defined objectives. Acknowledge these challenges, emphasizing the need for alignment with real-world complexities. Addressing these obstacles requires ongoing support, mentorship, and adaptive pedagogical strategies.

Projects in ecology and engineering serve as linchpins in promoting sustainable development by integrating ecological principles with engineering practices. In this symbiotic relationship, ecology provides a foundation of understanding regarding ecosystems, biodiversity, and the intricate interconnections within natural systems. Engineers leverage this ecological knowledge to design innovative solutions that mitigate environmental impact, conserve resources, and promote resilience. By incorporating ecological considerations into engineering projects, such as sustainable infrastructure design, renewable energy systems, and waste management solutions, practitioners can enhance sustainability outcomes (Dale et al., 2021).

Furthermore, the importance of rural education in Colombia cannot be overstated, particularly given the disparities and challenges that rural communities face. Addressing these educational gaps is paramount for fostering social equity, economic development, and environmental stewardship. Effective rural education initiatives can empower local populations with the knowledge and skills needed to engage in sustainable practices, contribute to community development, and address pressing environmental issues unique to rural areas. Thus, integrating ecological principles into engineering projects and prioritizing rural education initiatives are essential strategies for advancing sustainability efforts and promoting holistic development in Colombia.

# 5 Conclusion

The collaborative efforts of students across diverse academic disciplines from 2021 to 2024 underscore the importance of interdisciplinary approaches in addressing contemporary challenges. Through projects spanning fields like electrical engineering, mechanical engineering, mechatronic engineering, and agronomic engineering, students have demonstrated the value of cross-disciplinary collaboration in fostering innovation and problem-solving. Furthermore, the engagement of other fields such as social work, biology, business management, architecture, and anthropology highlight the interconnectedness of knowledge domains in tackling complex issues. By leveraging diverse perspectives and expertise, students have not only expanded their own skill sets but also contributed to holistic solutions that address societal, environmental, and technological needs. This period exemplifies the power of interdisciplinary collaboration in driving progress and advancing sustainable development goals.

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# Comparing motivation and reflection in project-work between TBL and PBL

Fernando José Rodríguez[1], Carlos A. Narváez-Tovar[1]

[1] Universidad Nacional de Colombia. Departamento de Ingeniería Mecánica y Mecatrónica. Sede Bogotá

Email: fjrodriguezm@unal.edu.co, canarvaezt@unal.edu.co

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**Abstract**

Project work in engineering courses prepares students with essential professional competencies, enables them to solve real problems, and develops critical skills for their future jobs. Given the challenges of executing projects with material products within tight deadlines, adopting suitable pedagogical approaches is crucial to the success of these projects. In this context, this study compares two pedagogical approaches in two courses with the same teacher in 2022 and 2023: Team-Based Learning (TBL) and Project-Based Learning (PBL), focusing on motivation, reflection, and learning. The students' perceptions were collected through an online survey. Responses came from 58/77 students for TBL and 56/78 for PBL, asking about their project-work experiences. The results demonstrate that both methodologies significantly enhance motivation and learning compared with traditional approaches. However, PBL uniquely encouraged more reflection and the practical application of theoretical knowledge. This analysis underscores the significance of tackling real problems and contexts, revealing that PBL provides a direct practical experience in engineering education. These insights are invaluable for educators and institutions aiming to refine their teaching methodologies, advocating for more integration of practical projects, and collaborative efforts into the engineering curriculum.

**Keywords**: Project-based learning; Engineering Education; Project Approaches; Motivation; Reflection.

## 1 Introduction

Education in the 21st century is experiencing significant cultural changes that imply an amotivation to study. For example, in Europe, it is approximately 11.7%, whereas in Colombia, 24.2% of young people aged 15–28 years are in tertiary education (DANE, 2023; Eurostat, 2023). This new culture requires the exploration of teaching methodologies that foster autonomy and personal development, resulting in high levels of motivation, and allowing students to acquire professional skills while remaining committed to the educational system. One methodology used to promote deep learning is Team-Based Learning (TBL), which follows a scheme similar to an inverted class and does not differ significantly from the structure of a traditional course. By contrast, problem-based learning (PBL) represents a more disruptive methodology regarding usual practices and promises to increase the learning of transverse skills. However, both methodologies must keep students motivated. In this article, we explore these two methodologies from the perspectives of motivation and reflection for learning. Initially, we reviewed the two methods. Subsequently, we explain the perspective used to interpret motivation and reflection based on the results of students' perceptions. Finally, we present the findings of this study.

## 2 Background

TBL is a pedagogical practice implemented in courses where students work as a team during sessions to reflect on a specific topic or the content of the subject. According to Michaelsen and Sweet (2008), TBL uses a scheme similar to that of the inverted class, in which students first prepare the subject assigned before addressing it in class. This method is divided into three stages: first, students study a particular topic; second, they participate in an individual reflection guided by the teacher; and third, they socialise reflection with their group, which remains constant throughout the course.

TBL is also a structured method for problem solving that is not limited to simple reflection. Sibley and Ostafichuk (2014) pointed out that TBL is designed to enable students to make group decisions about problems by applying concepts learned in class. Its structure is based on four principles: a) group training is organised and planned; b) students are responsible for their work; c) tasks are oriented towards learning and teamwork development; and d) members must actively participate and be prepared for group discussions. These principles, which are based on constructivist learning theories, are carefully considered during course design to achieve expected learning results.

TBL encourages motivation by allowing students to make their own decisions during discussions while the group is progressively structured. According to Haidet et al. (2008), although the evidence is limited, some studies show little effect or the need to integrate other practices, such as active learning and teacher accompaniment. However, the systematic work of the groups helps mature the group and refine their goals and collective commitments, which encourages the motivation to work as a team.

Project-based learning (PBL) is a pedagogical practice in which students solve a problem within the framework of a planned and structured project. De Graaff and Kolmos (2003), as well as Rodríguez-Mesa (2018) on groups in Colombia, identified six essential principles of PBL: a) The problem is the central axis and comes from real situations, b) is interdisciplinary, c) the student, who formulates and directs learning, d) is done in a group, e) is applied in a sociocultural context, and f) promotes exemplary learning. According to Kolmos et al. (2009), PBL adapts its models to the specific learning needs and institutional conditions of each course, varying the duration of time dedicated to solving problems according to their complexity, which may require from one day to several weeks.

Learning theories that underlie both methodologies, TBL and PBL, share the ideas of theorists such as Vygotsky and Bruner, but differ in how they address cognitive development. TBL considers that learning goes through stages from dualism to commitment, including multiplicity and relativism, in which individual opinions are discussed in a group, promoting the development of neural networks through emotional involvement (Sibley & Ostafichuk, 2014). In contrast, PBL sees learning as three-dimensional, covering cognitive, motivational, and social aspects, with a strong base in sociocultural theories, where students are actively involved in the resolution of real problems, interacting, and acting together (Illeris, 2018).

In the context of these two educational practices, we present a qualitative case study to understand the differences in motivation and reflection between them. We used two groups of students from different semesters who applied the same methodology to solve a problem and obtain a designed product. Using an online survey with an open-ended question, we examined the following research questions: What effect does the implementation of TBL and PBL have on students' motivation and reflection about the content of their projects? Consequently, how do TBL and PBL compare their effects on students' critical reflection and motivation?

# 3 Methodology

Two editions of the same course aimed at mechanical and mechatronics engineering students were implemented, in which they had to demonstrate the skills acquired throughout their career in the design of a mechanical product. These courses were developed during the second semesters of 2022 and 2023.

We employ an online questionnaire comprising an open-ended query to gather students' perceptions of their learning experience: "Please describe your experience in this course." This approach was selected to obtain unbiased information that could be thoroughly analysed. The anticipated responses were expected to provide pertinent data on the aforementioned questions.

The analysis of the responses was conducted from the perspective of Ryan and Deci's (2017) self-determination theory and Donald Schön's (1983) theory of reflection. We used Braun and Clarke's (2006) thematic analysis of students' responses to search for patterns related to motivation, autonomy, connection, competence, and reflection, typical of SDT for both PBL and TBL. We then examined how these patterns influence different types of student motivation, such as intrinsic and extrinsic motivation based on autonomy, competence, and connection. Likewise, the relationship between reflection and motivation was included in each model.

## 3.1 Self-determination theory

Self-determination theory (SDT) is a model of human behaviour that describes motivation as a continuum from controlled to autonomous (Ryan & Deci, 2017). This theory maintains that motivation is not a unitary phenomenon but a set of influences that psychologically impact the will of the individual. Motivation may reflect intrinsic interests, which arise from an individual's desires, or may be extrinsic, induced by external pressures that force activities that are not valued personally.

According to Deci and Ryan, autonomy is crucial in determining how these influences affect will; therefore, motivation, whether internally perceived through personal beliefs and experiences or externally perceived through the actions of a pedagogical process, plays a fundamental role in this aspect.

Beyond autonomy, this theory also identifies competition and relationships as the basic needs that complement an individual's motivation. Competition refers to the need to feel effective and capable, manifested through curiosity, manipulation, and various epistemic motifs. Conversely, a relationship implies feeling socially connected. This is related to the feeling that others care about one another, generating a sense of belonging and social importance.

## 3.2 Reflection as an indicator of learning

A central aspect that demonstrates that educational processes generate learning is reflection. According to Donald Schön, reflection can occur in two ways: "in action" and "on action." The reflection "*in action*" occurs when participants respond to unexpected situations, which implies a constant evaluation of the ongoing events. On the other hand, the reflection "*on action*" takes place when students review and analyse their past performances after an event has occurred, with the aim of improving future actions.

## 3.3 Applied Engineering Project (AEP)

The Applied Engineering Project is a crucial subject in the curriculum of mechanical and mechanical engineering. The course, which extends for 16 weeks, with a total of 192 school hours, is at the end of each program. Its objective is for students to apply their knowledge in solving a specific engineering design problem using methodologies backed by academic literature and appropriate for the type of problem to be solved.

The course generally hosts between 60 and 70 students, and is divided into three groups. The weekly structure of the course includes combined sessions: a two-hour general session for all groups, where common design-related issues are discussed, and separate sessions of tutoring, where each group works independently with a dedicated teacher, for monitoring and advice in the design process as necessary.

The AEP originally combined direct teaching with the realisation of projects during the first ten years. However, in 2020, a significant change was implemented in the PBL model during the pandemic. This new approach gave students the total responsibility to define and document an adequate mechanical design methodology. Using the principles of PBL, the model emphasised the declaration of the problem, selection of the methodology, and its development under the complete autonomy of students.

The students, grouped into teams of five members, selected a project in the first week of working with a real client. This allowed them to understand the problem deeply and address the solution in a group and autonomous manner. This model was implemented in direct education, as described below.

### 3.3.1 Team-Based Learning Model for AEP

The framework used in the creation of class activities is shown on the right side of Figure 1. Students must review the assigned documents for each class session, which are carefully chosen by the AEP teachers. To guarantee that students finish the assigned reading, a session guide containing activities will be planned and supplied to them during the session using various discretionary methods depending on the activity. Students will have a total of 10–12 minutes to complete the activity.

The guide is then delivered to the teacher or auxiliary student. Students will meet in group work and solve the same guide or questions as in the group's consensus. In no case did the group respond to the same or paraphrase of one of the group's deliveries. Then, clarification was made regarding the non-consensus of the group and a complementary presentation of 30 minutes. If there are more doubts or clarity, the complementary presentation is trimmed proportionally.

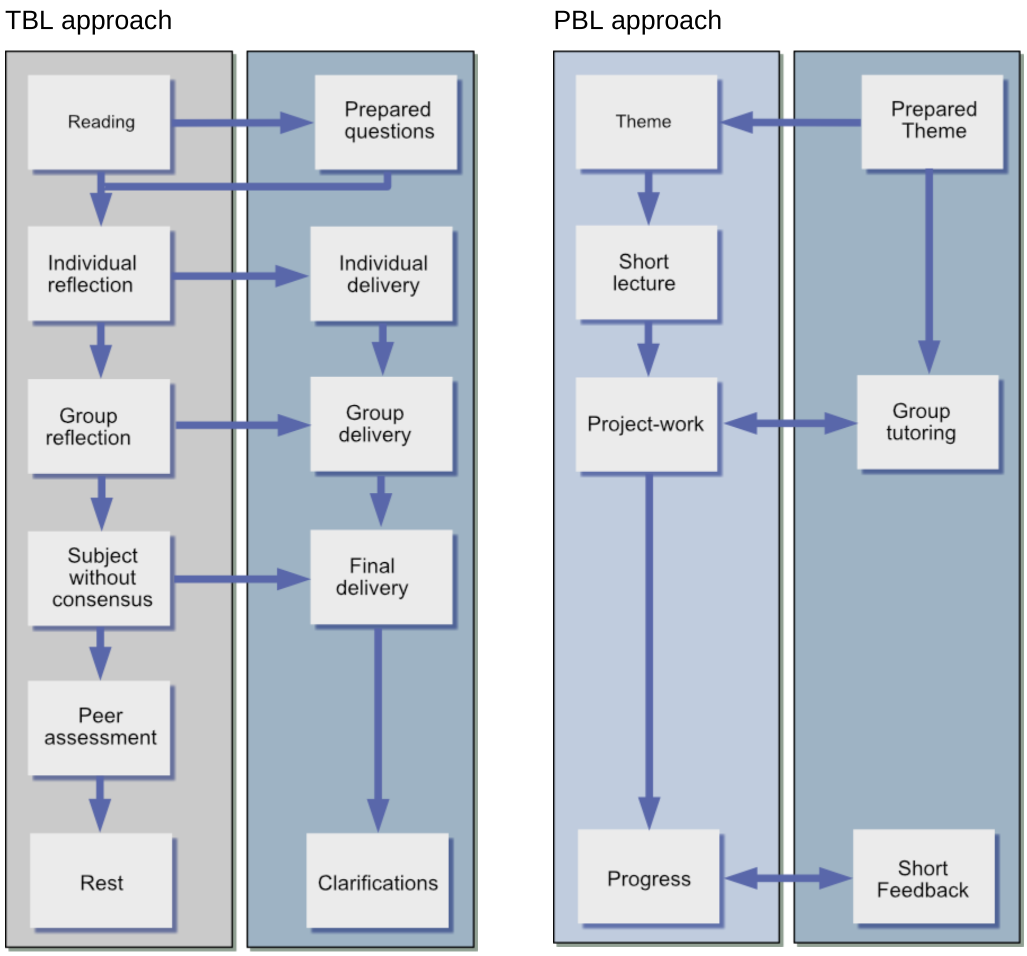


Figure 1. Scheme of a 2 -hour for TBL (left) and PBL (right) sessions

**General sessions:**

(Theory)

- Activity 0: 5 min - Presentation of the teacher's guide

- Activity 1: 15 min + 2 min Collection
- Activity 2: 40 min + 3 min Collection
- Activity 3: Peer assessment (5 min)
- Rest: 10 min
- Activity 3: Non -consensus clarification (15 min)
- Activity 4: Complementary presentation of 20-25 min

Tutoring sessions (Application for the project work)

- Activity 0: 5 min - Presentation of the teacher's guide
- Activity 1: Individual project activity 20-22 min
- Activity 2: Activity Project in Group 70-73 min
- Activity 3: Peer assessment (5 min)
- Activity 4: Clarification of non-consensus (15-20 min)

We designed 12 TBL activities that covered most of the system-design methodology. The reading materials required by the students were distributed at the beginning of the course and organised into a schedule of detailed reading activities. In addition, in each session, reflection questions were asked to encourage analysis and discussion among the participants.

### 3.3.2 Project-based Learning Model for AEP

The PBL model focuses on students' project-work. Two weekly group sessions of two hours each were included. In the first session, all students met in a room to discuss a topic that was aligned with the general design methodology schedule. By 2022, it will work with 78 students.

In this model, students are responsible for selecting the subject, formulating the design problem, and applying the design methodology to find a solution. As in the TBL version, students were expected to present the design product after 14 weeks of work on the project. Class sessions focused on general explanations and were dedicated most of the time to the autonomous development of the project by students. The teacher played the role of supervisor. The second column of Figure  illustrates this general procedure, which is less structured than the TBL model.

To avoid including dramatic changes in the processes that could influence the result, for both tests, the design methodology for the solution of the problem should be the design of the systems presented by NASA. (NASA SP-2016-6105 Rev 2, 2020).

# 4 Results

We collected 58 of the 76 possible responses for the TBL format and 56 of the 78 responses for PBL. In the TBL format of the course, a real problem was integrated. Specifically, during a session, the process described in the TBL methodology was followed, and in the following, it applied directly to the work of the project. This structure resulted in explicit comments from the students regarding their motivation. Some of the students' responses did not refer to the TBL or PBL models because they focused on difficulties with the group, especially in cases where they were excluded from the project work by the team members.

In the TBL model, a student commented on how working with a real project motivated the group to collaborate despite the challenges: "The development of the project was very enriching and the work with external parts was motivating; the work with the members of the group was productive and pleasant, and the final product had clear flaws, but an approach aimed at the target product. " Another student highlighted how the structure and process of course feedback favour the development of the project: "Being able to achieve the main objective was something very motivating for what I have left, the development of the course and accompaniment, [... ] because few teachers take the time to guide one and give feedback, in terms of group work made me grow academically and personally because I shared with very good classmates and personalities other than mine was interesting in addition to motivator. "

On the other hand, in the PBL model, students advance in each class session on the project, with only a few additional explanations. Motivation was influenced by the approach to a real project and freedom of thematic choice. A student said,' I liked Pai a lot because I could realise the lines that most attracted my attention from the career seen holistically, it helped me to discover my preferences, and I liked the project a lot because it motivated me a lot to follow working with it once the subject of AEP ended. " Another added: "I honestly liked the project because I could implement many of the knowledge of the career and also the engineering skills, there were many things that did not remember how they were done, and only by reviewing a few notes, I managed to understand and remember."

In TBL, autonomy is remarkable, but seems to be more structured within the team's activities. A student mentioned: "The topics presented in class contributed great methodological aspects to the management of our project and the specific research for the project has generated new interests in technologies and tools." This observation suggests that although autonomy exists, it is guided by the structure of the course and the activities of the team.

Autonomy and personal exploration are fundamental in PBL. A student stressed: "He was also very challenging personally because I had to look 'real' project and play a role within him that I feel he had a lot of involvement in the final result. " This demonstrates that PBL allows students to make independent decisions and apply their knowledge in a practical and significant manner.

In summary, while TBL provides a structure that guides student participation, PBL offers more space for autonomy and personalisation of learning, which is crucial for student motivation and commitment.

In TBL, the connections between team members are strongly emphasised through collaboration. One student stressed, 'There was very good communication between all members, and although there were differences in ideas, everything was decided diplomatically and objectively'. Effective communication and collective decision making strengthen the link between team members, highlighting the importance of cooperation and understanding.

In PBL, although the connection is equally important, it seems more oriented towards interaction with the external context of the project. The relationship between professionals and the application of their work in real situations plays a crucial role. As a student said: "Work with external parts was motivating, the work with the group members was productive and pleasant." This indicates that in PBL, in addition to internal collaboration, connection with the external environment and practical relevance are essential components that motivate and enrich educational experience.

Regarding *reflection in the action*, on TBL, students experience continuous adaptation to solve problems. A student commented: "The project flowed very well, there were problems that were solved throughout the semester." Another added: "During the sessions, we frequently adjust our strategies based on how the project evolved."

In PBL, about the *reflection in* the action, a student stressed: "He was also very challenged personally because I had to look for ways to reach several results in the best way." Another said: "I was constantly evaluating and reassessing my methods as new challenges arose."

In TBL, *reflection on* action is a crucial part of learning, as a student's comment shows: "Seeing the evolution of the project from its conceptualization was incredibly satisfactory and rooted in the love of the career and the potential of it for me for my profession".

In PBL, students *reflect on* their experiences and results after their occurrence. An example is the comment: "Work with external parts was motivating, the work with the group members was productive and pleasant." Another student reflected: "At the end of the project, I evaluated how my contributions could have been more effective", indicating a detailed consideration of their actions and results.

# 5 Discussion

The main difference between TBL and PBL lies in how each approach motivates the students. In TBL, motivation arises when working with real problems within a team structure where the challenges are approached collectively. However, in PBL, motivation is influenced by individual autonomy and the challenges of the real project, with students motivated by the opportunity to directly apply their skills to complex and real problems, implying more personal and self-directed learning.

Regarding autonomy, students' responses suggest that PBL tends to foster more autonomous motivations because of its structure which allows greater autonomy and opportunities for students to pursue their interests and significantly apply their knowledge. In contrast, TBL, although effective, offers fewer opportunities for personalisation and application of learning in real contexts.

The PBL link extends to the relationship with the external context of the project, whereas the TBL link focuses more on the internal collaboration of the team. In terms of competition, TBL focuses on the understanding and application of the thematic structure of the designed exercises, whereas PBL develops around the application of previous knowledge and the solution of practical problems.

Both methods incorporate elements of reflection; however, there are notable differences in how and when this reflection occurs. In TBL, reflection is more structured and oriented towards group problem-solving. In PBL, reflection is more autonomous and integrated with the individual application of theory to practice, promoting individual *reflections on* actions. This could indicate that PBL offers more opportunities for personal development through reflection, while TBL promotes reflection, which strengthens collaboration and interpersonal skills.

Finally, PBL can be more effective in developing reflective professionals who can evaluate and adapt their behaviour autonomously. Meanwhile, TBL could be more appropriate for those who benefit from structured reflection in a collaborative environment, promoting the improvement of teamwork and collaborative strategies. Ultimately, PBL facilitates an environment in which students can act as reflexive professionals, continuously evaluating and adjusting their approaches, while TBL promotes reflection as a means of improving the collaboration and effectiveness of the team in problem-solving.

# 6 Conclusion and Future Perspectives

The two pedagogical practices have different effects on student motivation. On one hand, TBL has a structure that favours motivation when the group's composition is recurring and the activities carried out are around the same project during the semester. According to this case study of TBL, the integration of real problems during the sessions motivated students to collaborate and overcome challenges. Students' comments highlighted that the experience was useful for their personal and motivational development, driven by the structure of the course and continuous feedback. This same structure favoured the reflection process, but limited it to the improvement of teamwork to enhance the assigned activities.

On the other hand, with less structured activities in curricular design, the PBL approach stood out for promoting greater autonomy, confirming students' learning principles, allowing students to make critical decisions, and applying their knowledge to complex problems. Thematic freedom and connections to real problems intensify motivation and commitment. However, these two approaches require an increase in the number of feedback cycles.

Based on these results, it is recommended to adopt TBL and PBL approaches to incorporate more TBL flexibility and a more collaborative structure in PBL, looking for a balance that maximises the strengths of both methods. The implementation of a real project on TBL that accompanied all activities could have a strong impact by increasing the motivation of the group.

A combination of TBL and PBL can have beneficial effects on online education. When there are real work limitations or difficulties in face-to-face meetings with students, as happened in the pandemic, the combination of these two methods, which highlights the approach of PBL autonomy and the challenge of the project, with online activities of TBL that allow structuring and favouring the remote participation of the students, could have an impact on new educational models.

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# Transferable Skills Development through Project-Based Learning in an Industrial Engineering and Management Degree

Violeta Carvalho[1,2,3,4], Cristina S. Rodrigues[1], Senhorinha Teixeira[1], Ângela Silva[1], Rui M. Sousa[1], Lino Costa[1], Anabela Alves[1], Carina Pimentel[1]

[1] ALGORITMI/LASI Research Center, School of Engineering, University of Minho, Guimarães, Portugal
[2] Mechanical Engineering and Resource Sustainability Center (MEtRICs), University of Minho, Campus de Azurém, Guimarães, Portugal
[3] Center for MicroElectromechanical Systems (CMEMS UMinho), University of Minho, Campus de Azurém, Guimarães, Portugal
[4] LABBELS—Associate Laboratory, 4806-909 Braga/Guimarães, Portugal

Email: violeta.carvalho@dps.uminho.pt, crodrigues@dps.uminho.pt, st@dps.uminho.pt, asilva@dps.uminho.pt, rms@dps.uminho.pt, lac@dps.uminho.pt, anabela@dps.uminho.pt, carina.pimentel@dps.uminho.pt

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**Abstract**

In the literature, transferable skills refer to the ability to learn and apply knowledge, skills, and attitudes in various professional contexts to solve real-world problems, always taking ethical values into account. Due to job market demands, it becomes imperative to promote these skills in Industrial Engineering and Management (IEM) students, and the active learning strategy Project-Based Learning (PBL) is an excellent opportunity to do so. Since 2004/05, the Department of Production and Systems (DPS) of the Engineering School, University of Minho (UM), Portugal, has been implementing PBL with students of the IEM Degree. In each of the three years of this degree, there is a semester-long Curricular Unit (CU) of PBL integrated project in IEM, namely IPIEM I, IPIEM II, and IPIEM III. Each of these projects involves the other CU of the respective semester. The main purpose of this paper is, based on a published framework of 23 transferable skills, to identify the extent to which each of these projects promotes the development of these skills, thus detecting strengths and weaknesses, and proposing possible improvement actions. It also aims to verify whether there is an evolution in the development of some of these skills throughout the IEM Degree. This exploratory study provides valuable teacher-centric insights, highlighting the need for incorporating student perspectives to enrich the understanding of PBL's impact on the educational process.

**Keywords:** Industrial Engineering and Management; Active Learning; Project-Based Learning; Transferable Skills.

## 1 Introduction

Transferable skills, i.e. the abilities adaptable across various tasks and contexts, form the foundation of professional capability. These skills, including communication, problem-solving, and teamwork, empower individuals to overcome challenges, collaborate effectively, and succeed in diverse environments (Pinto et al., 2023).

In the scope of the Industrial Engineering and Management (IEM) area, where multidisciplinary approaches and problem-solving are central, the development of these skills is particularly vital for success both during higher education and in future careers. They are not typically taught in a traditional classroom setting but are developed through experiences such as extracurricular activities, internships, part-time jobs, interactions with peers and mentors, as well as through active learning methodologies. The latter prioritizes student engagement, participation, and application of knowledge, fostering a deeper understanding of concepts and better retention of skills (Blinkoff et al., 2023; Wu et al., 2024). By integrating active learning strategies into the educational context, institutions aim to equip students not only with technical know-how but also with the versatile skill set necessary for success in the dynamic field of industrial engineering (Balalle, 2024; Kalu et al., 2023; Quibrantar & Ezezika, 2023).

This type of methodologies, such as problem-based learning, project-based learning (PBL), collaborative learning, and experiential learning, provide students with opportunities to develop and refine transferrable skills in real contexts. For instance, in problem-based learning scenarios, students are tasked with solving real-world engineering problems, requiring them to apply critical thinking, creativity, and teamwork to develop viable solutions (Dunmoye et al., 2024; Navío-Marco et al., 2024). Similarly, PBL assignments challenge students to manage projects from conception to completion, enhancing their time management, communication, and leadership abilities along the way. By actively engaging in these learning experiences, students not only deepen their understanding of theoretical concepts but also develop the transferrable skills necessary for success in professional life. Moreover, the interactive nature of active learning methodologies promotes collaboration, communication, and adaptability, skills that are highly valued in engineering practice. As a result, the integration of active learning approaches into higher education curricula not only enhances academic outcomes but also prepares students to surpass the complexities of the IEM area by equipping them with a robust toolkit of transferrable skills (Chatpinyakoop et al., 2024; Zhang et al., 2024). For instance, Zen et al. (Zen et al., 2022) explored the impact of Project-Based Online Learning (PBOL) and student engagement on academic achievement in higher education, with a focus on preparing graduates for the job market. The results suggested that PBOL and student engagement positively influence academic performance while entrepreneurship was fostered by having entrepreneurship lecturers. Marnewick et al. (Marnewick, 2023) identified several transferrable skills (analytical/critical thinking, communication, problem-solving, time management, teamwork, and project management) after a PBL implemented at a South African university. Similarly, Cicmil and co-workers (Cicmil et al., 2006) identified critical thinking, self-management of time, adaptability; problem-solving, communication skills, and interpersonal skills.

PBL methodologies have been implemented since 2004 in IEM programmes of the Department of Production and Systems (DPS) of the Engineering School, University of Minho (UM), Portugal, where transferable skills are inherent (Lima et al., 2007). The primary objective of this research is to analyse the progressive development of transferable skills in the IEM Degree students as they experience the three PBL projects offered throughout the course. Firstly, the three project CU are described. Then, based on the literature, the set of transferable skills is presented. Finally, using the previous information and the teachers' perceptions (mainly), the level at which these skills are considered in each project is assessed. The results include the identification of aspects to be improved in each of the projects, the proposal of concrete actions in this regard, and the finding that there are transferable skills that are improved throughout the three projects.

## 2 Study Context

Since the academic year of 2021/2022, a new study plan was implemented in the IEM Degree at DPS-UM. This new plan incorporates three semestrial Curricular Units (CU), one per year, entitled Integrated Project in IEM I, II, and III (IPIEM I, IPIEM II, and IPIEM III), as they integrate, as Project Supporting Courses (PSC), the remaining UC of the respective semester. In fact, the adoption of PBL at DPS, UM dates to 2004, when the first edition of an IPIEM was held, even without being included in the course's curricular structure.

The main teaching objectives of these IPIEM CU can be summarised as:

- Development of technical skills by applying the syllabus contents of the PSC in the context of the project.
- Development of transversal skills in a team-based environment.

The main aim of this initiative was also to provide students with a learning environment that encourages investigation, critical thinking, teamwork, problem-solving skills, and hands-on activities. Furthermore, the execution of the projects poses several challenges to students in terms of project management, task planning, meeting deadlines, communication, and teamwork.

## 2.1 IPIEM I

The IPIEM I is included in the IEM program of the first semester, first year. The semester has six CU, each holding five European Credit Transfer System (ECTS) (1 ECTS means 28 hours of student work) (Figure 1). All CU contribute as PSC for the project development using PBL approach. PSC of Engineering School are four: Computer Programming I (CP I), Integrated Project on Industrial Engineering and Management I (IPIEM I), Introduction to Economics Engineering (IEE) and Introduction to Industrial Engineering and Management (IIEM). The PSC from the Sciences School are Calculus for Engineering (CE) and Linear Algebra for Engineering (LA). This means the first year includes Science, Technology, Engineering and Mathematics (STEM) CU that must be integrated in an interdisciplinary project to solve the challenge provided (Alves et al., 2019).

| Regime | Curricular Unit | ECTS |
|---|---|---|
| Year 1 | | 60 |
| S1 | Calculus for Engineering | 5 |
| S1 | Computer Programming I | 5 |
| S1 | Integrated Project in Industrial Engineering and Management I | 5 |
| S1 | Introduction to Economics Engineering | 5 |
| S1 | Introduction to Industrial Engineering and Management | 5 |
| S1 | Linear Algebra for Engineering | 5 |

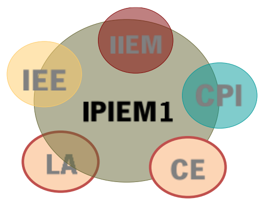


Figure 1. Curricular units of first year, first semester of IEM Degree (adapted from UMinho (UMinho, 2023))

IPIEM I project theme have been always focused on sustainability issues (Alves, Moreira, et al., 2017; Colombo et al., 2014, 2015; Moreira et al., 2011). The 2023-24 edition was no exception, addressing the design of a production system for sorting, remanufacturing, revalorising and/or recycling end-of-life electric scooters, including all the aspects related to the development of the new products.

The IPIEM I project involved teachers from different courses, voluntary tutors (department lecturers and third-year IEM Degree students) and, sometimes, voluntary educational researchers in a total of 21 team members to manage this edition. The project is regularly developed in the first semester, i.e. from September to January. Team coordinator first step is to have a meeting, before classes starting (first week of September) to define the project management (time, resources, theme and so on). More details are provided in Alves et al. (2021).

In the first week of classes (11 to 16 of September), the project is presented to freshman students, which arrived at university one week before, in a session organized by the coordination team. The presentation has the following points: (i) Framework; (ii) History of PBL projects, motivation, and some alumni testimonials; (iii) Coordination team; (iv) Learning project guide including tutors' role, milestones and deliverables, assessment methodology, project theme, presentation of the pilot project, plan, and schedule first and second week, operation and use of project rooms and, finally; (v) Formation of teams and assignment of tutors. The learning project guide is a word document prepared by the coordination team for students to read and follow, explaining all details of PBL process organization, coordination team contacts, learning outcomes expected from each course, time schedules, tutors' role, among others important elements (Alves et al., 2021). In this edition, 68 freshman students were organized in eight teams of eight to nine members.

In the courses regular classes, it was better explained what student teams should do (project related tasks) to contribute for the project development in IPIEM I. Each course defines the tasks and its contents, but the idea is to integrate all or almost all contents in the project development (Alves et al., 2019). With this project, students must develop not only technical but also transversal competencies.

IPIEM I assessment included some deliverables that were presented in specific milestones (M) during the semester, as illustrated in Table 1. This is a time-consuming task for coordination team; however, it is important to have assessment *for* and *as* learning through the project development (Fernandes et al., 2012, 2021). The team assessment counts for 90% and the remaining 10% comes from a triad challenge, named IEM@ProjectNetworking (Alves et al., 2013, 2022).

Table 1. IPIEM I milestones, deliverables, and weight of each in the assessment methodology.

| M | Date | Deliverables | Weight |
|---|---|---|---|
| 1 | 2023.09.20 (Week 2) | 09h10 – 12h00: Pilot-project presentation (10'/team + 5' discussion) | Not assessed |
| 2 | 2023.10.18 (Week 6) | 09h10 – 12h00: Team progress (10'/team) + enlarged tutorial (15'/team). | 7,5% (team) + not assessed |
| 3 | 2023.11.14 (Week 9) | 09h10 – 13h00: IEM@ProjectNetworking result (5´/pair) | 10% (triad) |
| 4 | 2023.12.01 (Week 12) | 18h00 – Preliminary report (30 pages maximum). | 25% (team) |
| 5 | 2024.01.03 (Week 14) | 18h00 – Final report (40 pages maximum) | 40% (team) |
| 6 | 2024.01.08 (Week 15) | 09h00 – 17h00: Final presentation and discussion (15'/team+ 30' discussion) + blog + Padlet | 12,5% + 7.5% + 7.5% (team) |

## 2.2 IPIEM II

The implementation of the Integrated Project of the 2nd year of the IEM Degree took place for the first time, in the academic year of 2021/2022, and comprises four different CU of the 4th semester. These are Complements of Applied Statistics (5 ECTS), Operational Research and Optimization (5 ECTS), Numerical Methods (5 ECTS), and Information Systems and Technology (5 ECTS). The coordination team includes the project coordinator the teachers involved in the four CU. The technical skills given by these four subjects dictates the project main characteristic of challenging students to deal with real data, requiring learning skills from the CU involved: applying statistical data analysis techniques, database manipulation and management tools, and implementing software solutions related to data processing/analysis.

For this project, the students are organised in teams of 8 to 10 members. Along the three years of project implementation, the engineering problem proposed to the teams have been changing. In its first year of implementation (academic year of 2021/2022), each team had to select a theme and obtain real databases about the topic from the internet. The team's challenge was the treatment of the data following and combining the different objectives of each subject (Carvalho et al., 2023). In the second year (academic year of 2022/2023), the project had the Climate Changes as a common topic. Each team had to define the subject (for example, forest fires, air quality, and extreme weather events) and to get a dataset available online. In the current year (academic year of 2023/2024), the project has an investigation problem concerning the definition of an efficient supply chain system for an article from an industrial sector in the northern region of Portugal. The team's challenge is to contact a business company to be a partner of the project and to give them access to supply chain data. The aim of this methodology is to give to the second-year students a more holistic and integrated knowledge and understanding of this engineering topic and its relevance to the real world.

In the first two editions, the project teams were formed by students. In the academic year of 2023/2024, 72 students attended IPIEM I and were organised into nine teams of eight students. To develop teamwork skills, this academic year, students faced a new challenge aspect related with the team composition and teamwork, since the teams were formed by a drawing of the member of each team. In this new context, the "natural" groups (i.e. teams formed by the students themselves, eventually according to their friendships) were intentionally discontinued.

IPIEM II assessment includes a poster presentation and discussion (10%), an intermediate report (20%), a final report (40%), and a final presentation and discussion (30%).

## 2.3 IPIEM III

The most recent edition of IPIEM III CU took place in the second semester of 2022/23, with 69 students divided into seven teams. Following a PBL approach, IPIEM III involved, as PSC, all the remaining CU of the semester, namely Data Analytics (5 ECTS), Decision Models (5 ECTS), Logistics and Supply Chain Management (5 ECTS), Manufacturing Planning and Control (5 ECTS), Project Analysis in Industrial and Engineering Management (5 ECTS). The coordination team was made up of six teachers, one per CU.

The student teams were exposed to an industrial scenario created by the coordination team (based on real contexts), in which a fictitious company faces a considerable increase in demand for three of its product families. Therefore, the company will have to increase its production capacity to be able to respond in a timely manner to new orders, ensuring, in the best possible way, not only the quality of the products, but also low production costs. The general challenge for each student team is to develop proposals / plans at various levels, namely in terms of equipment and labour requirements, logistics, production planning and control and information systems, so that the company's objectives can be achieved.

IPIEM III assessment include two oral presentations, intermediate presentation/discussion (10%) and presentations/discussion (15%), a final report (65%) and the presence on seminars (10%), with invited speakers, about different subjects related to the project.

# 3 Materials and Methods

The methodology used to analyse transferable skills in the three PBL projects under study (IPIEM I, IPIEM II and IPIEM III) comprised four main steps:

(1) literature review and selection of transferable skills – it was adopted a framework of 23 transferable skills identified by (Ferraz & Pereira-Guizzo, 2023), due to their relevance to the IEM area, and potential to be developed through PBL projects;

(2) document analysis – analysis of the material describing each project (e.g. project guide and institutional course catalogue) to identify the transferable skills thought to each project;

(3) assessment of teachers' perspective – a team for each project held a session to collect their perception on how the respective project promoted the development of the 23 transferable skills. The assessment was made using the scale: (--) not developed; (-) poorly developed; (+) somewhat developed; (++) developed;

(4) data discussion – the data provided by each coordination team was aggregated and used to identify the most and least developed skills not only in each project, but as a whole, in order to identify weaknesses and strengths.

# 4 Projects Assessment

## 4.1 IPIEM I

In addition to the specific skills of the curricular units involved in the IPIEM I, students have the opportunity to develop a set of transferable skills. Through the analysis of the IPIEM I guide, it could be found that the coordination team organised the set of transferable skills into four strands: (1) project management skills, including research capabilities, decision making, organization and time management; (2) personal development skills, namely creativity, critical thinking, self-evaluation and self-regulation; (3) team work, entailing autonomy, initiative, responsibility, leadership, problem solving, interpersonal skills, motivation and conflict management, and (4) communication skills, written and oral.

It can be concluded that there is an alignment between the skills listed in the students' guide, presented in section 4.1, and those proposed by (Ferraz & Pereira-Guizzo, 2023). In the IIEM course students learn several techniques related to project management and teamwork that they are expected to explore and practice in the IPIEM I project development. Furthermore, since students need to project a new product and the respective production system, creativity skill, collaboration with the group and assertiveness have been greatly developed. In addition, critical thinking is another skill developed (Alves et al., 2023). The team members must negotiate and achieve consensus on several decisions to be made.

Also, from the deliverables presented in Table 1 (section 2.1), the students develop public speaking skills, as they have three presentations and being assertive during those presentations to argument to teacher's questions. They also develop written communication as they have two reports as deliverables in IPIEM I and, at least, three more brief reports of tasks performed on IEM Degree. Teachers gave them feedback on the first report delivered and on the tasks. In addition, the coordination team used a Padlet where the teams must continuously write the current state of the project during the whole semester.

PBL in IEM has been fundamental to develop such skills as well as social skills as IEM alumni has been testifying (Alves, Leão, et al., 2017; Araujo & Manninen, 2021; Marinho et al., 2021). Nevertheless, a great potential for development exists related to tasks division as the project is complex and the students do not have the skills needed to share the learning between the team members.

## 4.2 IPIEM II

The project is developed during the semester and the teachers from the four CU provide tutorial support. Apart from the technical skills of the CU that integrate the project, students must acquire transversal skills, as they have to:

- develop an interdisciplinary team project;
- solve multidisciplinary industrial engineering problems involving real data;
- develop teamwork skills in a project environment.

IPIEM II provided a learning environment where students could develop critical thinking, by identifying and solving real-world problems. They learned how to analyse data, make decisions, and work in randomly generated teams. The latter fostered collaboration by requiring students to work effectively in teams with diverse personalities, and drive progress within their teams, reflecting the dynamics of a professional setting. The project also encouraged students to be independent learners and fostered a growth mindset, through preliminary report evaluations in order to turn mistakes into learning opportunities, encouraging a culture of continuous improvement. Furthermore, students were expected to be proactive, and act ethically within diverse teams. On the other hand, time management was enhanced through meeting attendance and deadlines. Finally, both written and verbal communication were developed as well as logical reasoning abilities while presenting/defending their work.

While IPIEM II effectively addressed many transferable skills, students had limited opportunities for developing persistence, adaptability, conflict mediation, active listening, and collaborative solution building. Additionally, encouraging practices such as stimulating collaboration, recognizing contributions, respecting differences, and offering help to colleagues would further enhance the program.

## 4.3 IPIEM III

Teamwork (with project planning and progress presentations) promotes the development of project management and transferable skills. With regard to the previously mentioned set of transferable skills, the design of IPIEM III aimed to develop the following:

- Autonomous learning – each team should investigate/identify some necessary data and concepts, intentionally missing in the scenario, in order to develop the project;
- Proactivity – students must be proactive by anticipating eventual problems and devising possible countermeasures;
- Openness toward receiving criticism and feedback – during the oral presentations and the development of the tasks, the students receive feedback from the teachers and colleagues;
- Public speaking – two oral presentations (intermediate and final) are mandatory during this project;
- Written communication - at the end of the project each team must write a final report with the integration of all the tasks developed;
- Recognition for contributions – the team develop peer evaluation, just before the two presentations, so members recognize their own work and the contribution of each member of the team;
- Ethics and professionalism – at the beginning of the project, the coordination team develop a schedule for the project with four milestones to promote the accomplishment of the project on time.
- Collective construction of solutions and Collaboration with the group - to promote the teamwork and the development of collective solutions teams with 8 students are created randomly and the collaboration between the team members is also promoted.

During the IPIEM III development, the coordination team promote a few seminaries with professionals about the subjects/areas involved on the project, that are mandatory for all the students. This is an opportunity for the students to interact and learn with professionals from different areas of expertise.

## 4.4 Results Discussion

This section presents, in table 2, an aggregated perspective of teachers' perceptions about the development of the 23 transferable skills (Ferraz & Pereira-Guizzo, 2023) in the three projects, followed by the corresponding discussion, encompassing problems identification and improvement proposals.

Table 2. Transferable skills identified in each project.

| Course Unit<br>**Transferable Skill** | **IPIEM I** | **IPIEM II** | **IPIEM III** |
|---|---|---|---|
| Identification of critical points for the work | - | ++ | + |
| Expression of creativity | ++ | + | -- |
| Logical reasoning ability | - | + | + |
| Persistence | + | - | -- |
| Adaptability | - | - | - |
| Autonomous learning | + | + | ++ |
| Willingness to help colleagues | - | - | + |
| Proactivity | - | + | + |
| Attendance | -- | + | -- |
| Meeting deadlines | + | ++ | + |
| Respect for differences | -- | - | ++ |
| Collaboration with the group | ++ | + | + |
| Ethics and professionalism | -- | + | -- |
| Collective construction of solutions | - | - | - |
| Stimulating collaboration | + | - | + |
| Recognition for contributions | ++ | - | ++ |
| Written communication | + | ++ | ++ |
| Assertiveness | ++ | + | ++ |
| Active listening | + | - | - |
| Public speaking | ++ | ++ | ++ |
| Conflict mediation in the group | - | - | - |
| Learning based on the recognition of one’s own mistake | - | + | - |
| Openness to receive criticism and feedback | - | + | + |

Legend: (++) Developed (+) somewhat developed (-) poorly opportunity to develop (--) Not developed.

By observing Table 2, one can see that public speaking skill stands out across the three projects. With frequent presentations and engagements, students have had several opportunities to refine their communication abilities. These experiences extend beyond the classroom, fostering coherent, confident, and persuasive communicators. Regular feedback further enhances this skill, ensuring continuous improvement and effective communication in both academic and professional contexts. However, amidst the developed skills, certain areas require greater attention. Collective construction of solutions is hindered by a tendency to divide tasks. To address this, integrating team-building exercises and individual assessments covering all subjects within a project can foster a sense of collective responsibility and collaboration. Additionally, conflict mediation within groups lacks effective tools, resulting in unresolved tensions. Implementing workshops focused on conflict resolution techniques and integrating more team-building activities can equip students with practical skills to manage conflicts constructively, fostering a balanced academic environment. In addition, adaptability, attendance, and ethics and professionalism are other critical transferable skills highlighted in Table 2. Adaptability can be developed through exposure to varied tasks and challenges within the projects, encouraging students to quickly adjust to new situations and requirements. Encouraging regular attendance is crucial for instilling discipline and a strong work ethic. This can be achieved through clear expectations and consistent enforcement of attendance policies. Ethics and professionalism can be fostered by including discussions on ethical dilemmas and professional conduct within the curriculum, and by demonstrating these behaviours through faculty and industry mentors.

In conclusion, while public speaking thrives due to regular practice, collective problem-solving and conflict mediation require targeted interventions. By implementing strategies such as team-building exercises, individual assessments, conflict resolution workshops, and emphasizing adaptability, attendance, and ethics and professionalism, educational institutions can foster a wide range of skill sets among students. These efforts prepare them for academic success and future career challenges.

In short, the different IPIEM projects gave students the opportunity to develop various transferable skills that will be valuable to succeed in the workplace.

# 5 Conclusion

This exploratory study shows the first attempt to concurrently examine the three projects applied throughout the Industrial Engineering and Management Degree at the University of Minho, and it provided valuable insights into the educational process involved. However, it is important to note that this evaluation solely reflects the teachers' perceptions. Thus, the next step involves exploring the students' viewpoints to enrich the analysis and deepen our understanding of PBL dynamics within the educational context. Finally, continuous evaluation and refinement of PBL approaches will allow the teachers' teams to create a more enriching and effective learning environment that fosters both individual and team growth over the three years of the Degree.

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# Technologies and interdisciplinarity to rescue cultural heritage

Gerardo Salvador González Lara[1], Carolina Sacristán Ramírez[2], Paloma Vargas Montes[3]

[1] Department of Humanistic Studies, School of Humanities and Education, Campus Monterrey, Tecnologico de Monterrey, Mexico
[2] Department of Humanistic Studies, School of Humanities and Education, Campus Monterrey, Tecnologico de Monterrey, Mexico
[3] Department of Humanistic Studies, School of Humanities and Education, Campus Monterrey, Tecnologico de Monterrey, Mexico

Email: gsgonzal@tec.mx, csacristan@tec.mx, palomavargas@tec.mx

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**Abstract**

It is strategic to establish a bridge between society and engineering education. Tec de Monterrey's Educational Model is based on disciplinary and transversal competencies, and Challenge-Based Learning. A humanistic training course with transversal competencies was designed for engineering careers; students applied various information technologies to recover and promote the cultural heritage of Monterrey, Mexico. The methodology to validate this innovation was based on the research assumption - not hypothesis -: "Students will develop to a greater extent the transversal competencies integrated to their curriculum by applying technology to recover and promote the cultural heritage of the city". The assumption was demonstrated and validated by investigating the level of development and assessment of these transversal competencies with Olivares (2018) instrument and two others with qualitative and quantitative approaches. The general objective was: Incorporate the use of information technologies to real projects for the recovery and dissemination of cultural heritage; and five other specific objectives. The transversal competencies: 1) Use of Technology, 2) Intellectual Curiosity and 3) Professional Impact. It was implemented in February - June 2022 with two student groups. A course was designed with concepts, lectures, activities and field immersion. The result was a positive development of competencies and the objectives were achieved. Nine multimedia productions were produced for the Historical Archive of the Archdiocese of Monterrey, the Museum of Sacred Art and the Basilica of Monterrey. This innovation was replicated with six more groups; in addition, the digitization of historical archives was added. Engineering students have achieved sensitivity and commitment to recover and promote cultural heritage. This didactic and research was nationally recognized as a Novus project and can be replicated in other universities.

**Keywords**: Interdisciplinarity, cultural heritage, technology, heritage.

## 1. Introduction

Currently, it is very necessary to establish a solid bridge between the needs of society and the teaching of the different engineering disciplines. This will be achieved through innovative didactic techniques that mark the future of the teaching/learning processes and the development of disciplinary and transversal competencies in future graduates. Simultaneously, in a globalized world, the cultural heritage of regions or collectives must be recovered, safeguarded and promoted in order to generate identity and a sense of life for present societies, and at the same time, respect for other cultural groups. That is why humanistic and citizenship training in future engineers is a very important complement within the curricula that is achieved by implementing active learning processes, and the definition and evaluation of the level of development of transversal competencies in students. This work shows the incorporation of humanistic and citizenship training courses for students of different engineering courses at Tec de Monterrey in real projects for the recovery, rescue and dissemination of cultural heritage and historical memory of their region. The innovation challenge has been to direct the use of technology with cultural heritage for the development of competencies. It had its origin, in turn, with another innovation called Week i: Craftsman of Music in 2018 and 2019, same (innovation) that was presented as a poster at the 7th. International Congress on Educational Innovation in 2020, and whose result is the following two links:

- Brief presentation, in Spanish: https://www.youtube.com/watch?v=YXuwrqrMUPE&feature=youtu.be
- Web page: https://orfebresmusicales.wixsite.com/orfebresmusicalestec

Week i consisted of an immersion of students from different careers to carry out a challenge for the development of competencies in only five days.

Phases and type of heritage for the challenge educational innovation project:

1. Week i September 2018: Sacred musical heritage. Musical craftsman: Jewels and musical treasures of the 19th century.
2. Week i October 2019: Secular musical heritage: Musical craftsman: Ode to nature.
3. February - June 2022: Artistic and architectural heritage. - Impact measurement was carried out in this semester.
4. August - December 2022: Documentary and bibliographic heritage with digitization of historical archives.

The third phase was in the semester February - June 2022 with two second semester groups of the subject Cultural imaginaries of Mexico. Subsequently this didactic has been carried out until 2024 with six more groups adding the digitization of historical archives.

This educational innovation changed from being one week in 2018 and 2019 to an entire semester starting in 2022 and distinguished as a Novus project. The design of this course, whose educational intention to incorporate technologies and interdisciplinarity to recover cultural heritage was recognized as a Novus Project of Educational Innovation, and within the top ten Novus courses across Tec de Monterrey nationwide. And what is a Novus project at Tec de Monterrey? According to the Institute for the Future of the Education - Novus of the Tecnológico de Monterrey (2022) Novus projects are courses designed in a disruptive way that have two axes: "firstly there is the educational innovation, the heart of the project, which will be implemented in one or more learning experiences; the second axis has to do with the experiment, which is oriented to formally measure the impact that the innovation has on some variable of educational or training interest". For this project, the "heart of the project" and challenge was to direct information technologies (ICTs) towards an area traditionally distant: cultural heritage for its recovery, rescue, valuation and promotion. This educational innovation will be explained in the following sequence: 2. Development, 2.1). Theoretical support of the didactic process, 2.2). Theoretical support of the academic discipline Cultural Heritage for the course Cultural Imaginaries of Mexico, 3) Implementation of the Innovation, 4) Evaluation of results, and 5) Conclusions.

## 2. Development

This educational innovation was implemented in the course Cultural Imaginaries of Mexico taught by the Department of Humanistic Studies to students of different engineering and professional careers of the Monterrey Campus of the Tecnológico de Monterrey during the semester February - June 2022. General objective: Incorporate the use of information technologies to real projects for the recovery and dissemination of the cultural heritage of Monterrey, Nuevo León, Mexico.

### 2.1 Theoretical and methodological basis of the didactic process and research.

The Tec de Monterrey Educational Model (2016) is based on the development of competencies and through challenge-based learning.

In this Model, competencies are understood as the conscious integration of knowledge, skills, attitudes and values that allow successfully facing both structured and uncertain situations and that may involve higher order mental processes. Competencies integrate both the knowledge and procedures of the 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: disciplinary 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 (6).

For this educational innovation it involved the following transversal competencies: 1) Intellectual curiosity, 2) Use of technology and 3). Professional impact. Following are the definitions (González et al., 2018):

1. Intellectual curiosity: Understood as a competence, intellectual curiosity should be framed, in line with the classification of, under the domain of the "Personal Knowledge Dimension", which refers to those traits of the individual's personality that guide his/her behavior and, consequently, have a determining influence on his/her autonomous actions and is closely related to the conduct and concrete actions of a person.
2. Domain of information and communication technologies (ICTs): Application of knowledge of the use of technology for the stated challenge.
3. Professional impact: Internalization of the objectives and competencies of the course for the short, medium and long term.

The Educational Model of Tec de Monterrey (2016) 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 relevant problematic situation, which involves the definition of a challenge and the implementation of a solution (10). Challenge-based learning is based on experiential learning, the principle of which is that students learn better when they actively participate in open learning experiences, instead of passively intervening 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 solutions and interact with other students within a given context (Moore, 2013). Experiential Learning is a holistic integrative approach to learning, combining experience, cognition and behavior (Akella, 2010). 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 prior authorization of the Academic Department Direction, and then the general objective and specific objectives are defined, both for students and teachers (Akella, 2010).

Research assumption: "Students will develop to a greater extent the transversal competencies integrated into their curriculum by applying technology to recover and promote the cultural heritage of the city".

General objective: To incorporate the use of information technologies in real projects of recovery, rescue and cultural diffusion of Monterrey, Nuevo Leon, Mexico and the northeastern region of Mexico.

Specific objectives considered as challenges for the students were:

1. to carry out for the Training Partner creative multimedia or multiplatform productions to promote their cultural heritage both in form and content.
2. To develop the competencies of the Training Unit of Cultural Imaginaries of Mexico of the Tec de Monterrey during the February - June 2022 semester.

Specific objectives considered as challenges for teachers were:

3. To design innovative didactics specifically for this course inside and outside the classroom, and with immersions to workspaces for active learning from the approach of a Challenge Based Learning.
4. Obtain and analyze results with the two measurement instruments.
5. Identify areas of improvement for future projects of similar innovation.

Development and evaluation of competencies. How was the level of development of the three transversal competencies evaluated during the didactic process of the course and elaboration of the challenge? With three measurement instruments: a) Mainly with the measurement instrument proposed by (Adame and Olivares, 2018) for the development of the three competencies. b) Self-evaluation instruments coevaluation designed by the teachers, and c) Institutional Student Feedback Survey (ECOA).

## 2.2 Theoretical basis of the academic discipline Cultural Heritage for the course Cultural Imaginaries of Mexico.

To overcome uncertainty, to build bridges between society and learning in the future, the environment close to the student and his community must be an instrument of teaching, learning and development of competencies to trigger cultural identity, memory and encounter with the cultural other. In the design of this didactic, the competencies to be developed must be identified and in a quantitative way demonstrate its formative impact for the possibility of replicating this didactic in more students (Gutiérrez, V.M et al 2017 and 2018). We agree with Innovation and Social Entrepreneurship in Higher Education Institutions: Students4Change (2019) when considering relevant for the training of current entrepreneurs and social leaders, it is necessary to promote experiences in students [and teachers] that give testimony of social entrepreneurship and leadership whose actions benefit the present society and preserve the memory. What is the teacher's role in contrast to other educational models? From this perspective, the role of the traditional teacher is now also that of an advisor who shows confidence and respect for the diverse possibilities of development of each of his or her students, which moves him or her to seek the most effective way for them to achieve integral development (Ayala, 2002).

To understand the concept, recovery and safeguarding of cultural heritage, the following concepts are relevant to approach this innovation: culture, encounter with the other and cultural instruments.

The definition of culture by Gómez (Pérez, 2000) is used: "Culture refers to the common system of life of a people, which is the result of its history, of the adaptation between that human population and the environment in which it lives, and socially transmitted, a process that is carried out through productive techniques, through organizational structures at the economic, social and political levels, and through conceptions of life, of a scientific, mythological, ethical, religious, etc. type. Therefore, I define culture globally, embracing all the levels that compose the social system, in its complexity, interrelated among themselves, operating in a conscious and unconscious way". Regarding the Encounter with the other, according to Reyes Heroles (2003), knowing one's own culture and that of others is a way to conquer freedom. In the same way, inquiring into memory, into the past through cultural heritage in its different modalities, is an encounter with the other, that other of other centuries, of other generations, but who left a legacy for us in our present, to find our own identity; that self in search of meaning. Thus, this experience will propitiate the yearning to conquer freedom through our own knowledge of our cultural heritage and, in turn, of the other culturally different.

Cultural instruments. And how is culture constructed and perpetuated? Bonfil's methodological proposal (1987) proposes the concept of cultural instruments as a way to know a certain culture, because identifying them will give greater meaning to their presence and function. Cultural instrument: "Any collective act with a common social purpose, and they are pertinent to analyze a social group" (108) and can be identified or created within a cultural group: They are material, demographic: of organization: of knowledge, symbolic and of communication and emotional or subjective. They are of interest for the recovery of time, knowledge, space, speech and identity; and the synthesis of the previous recoveries for a reflection on the historical project of each cultural group.

This educational innovation is integrated to the interest of other colleagues in different parts of the world to use the different modalities of technologies with the same purpose: to value cultural heritage; as stated in Diaz, C. et al (2021) citing at least six cases, in addition to the one they expose: "Recently, digitalization has also permeated the reactivation of cultural heritage. The joining of Augmented Reality (AR) and digital cultural content has produced examples of recovery and revival of cultural heritage in Latin America and the world. It is a new area for these applications; cultural, heritage, and historical societies and museums have taken advantage of this technology to represent contents and uses. Augmented reality provides an excellent orientation and immersion of the user (tourist, visitor, or citizen) in the destination or the patrimonial or tourist resource. The user perceives information about the place being visited in a more real and interactive way". In turn, UNESCO (2014) in its Indicators of Culture for Development (IUCD) project "considers culture not only as a sector of activity, but also in terms of the values and norms that guide human action". To be aware that culture in its different manifestations generates cultural heritage so that its valuation is a guide to preserve the identity of all people in order to identify the meaning of our lives.

## 3. Implementation of Educational Innovation

For this educational innovation, teachers are committed to measure or investigate the impact on students with a data collection instrument for later analysis. In Table 1. Instrument for measuring the three selected transversal competencies in pretest and posttest, the instrument with the three selected transversal competencies in pretest and posttest is shown. From the instrument proposed by (Olivares, and Adame, 2018). Seven questions were selected from the 40 that the instrument must measure the impact and development of the three selected transversal competencies, and a survey was used for their measurement. This survey was answered individually; each question had an answer with a scale from 1 to 5, where 1 is the value that represents the least development of the competency: "totally disagree", and 5 is value that represents the highest development of the competency: "totally agree".

The table 1 below shows the three transversal competencies selected from the instrument and the questions that were written to measure the level of development of the cross-cutting competencies or variables of this research.

Table 1. Instrument for measuring three selected transversal competencies and their questions in pre-test and post-test.

| Transversal competence | Pre-test | Post-test |
|---|---|---|
| 1. Intellectual curiosity | I expect the selected activity to challenge me intellectually. | The activity challenged me intellectually. |
| | I expect to solve problems relevant to my professional development during the immersion semester. | I solved problems relevant to my professional development. |
| | I spend time searching for information to learn new topics. | I spent time searching for information to learn about the topic related to the activity. |
| 2. Use of technology | I expect to make use of technology in challenging activities. | I had the opportunity to make use of technology in the challenging activity. |
| | Time and resources are used efficiently in the projects. | Time and resources were used efficiently. |
| | I developed creative solutions to complex problems. | I developed creative solutions to challenging activities in this immersive semester. |
| 3. Professional impact | The organizations I have been involved with have benefited from my actions. | The organization we participated with benefited from our actions. |

Table 2. Chronology of the didactic process February - June 2022, shows the general schedule of the Novus course - Cultural Imaginaries of Mexico: February / June 2022.

Fifteen weeks of work divided into three periods of five. 40 students in nine teams with four or five members. The master classes are sessions with experts of recognized academic and professional trajectory, six were organized. Three didactically guided visits inside and outside the Campus to the spaces required for the project.

Table 2. Chronology of the didactic process February - June 2022. Names of invited persons marked with "XXX".

| **Period 1**<br>**Weeks 1 to 5** | **Period 2**<br>**Weeks 6 to 10** | **Period 3 - Workshop**<br>**Weeks 11 to 15** |
|---|---|---|
| Pre-test application.<br><br>Contents: Readings, concepts and learning activities and development of competencies per week.<br><br>Academic visits to: Museum of Mexican History, Museum of the Northeast, Museum of Contemporary Art, and to White Space- space for reflection (within the Campus).<br><br>Master class, 3/6:<br><br>1. XXX, PhD and Poet from Edge Hill University - UK.<br><br>2. XXX, B.A. in Communication Sciences (ExATec LCC) 1988 and M.A. in Education. Artist and cultural promoter, social entrepreneur.<br><br>3.Priest XXX, Director of the Historical Archive and Archdiocesan Museum of Sacred Art, and training partner. | Content: Readings, concepts and learning and competency development activities per week.<br><br>Immersion 1 in workspace. Explanation by teachers, specialists and training partner of the spaces and objects of study. Sessions at different times for the convenience of student groups.<br><br>Teacher XXX, curator and responsible for the Archdiocesan Museum of Sacred Art.<br><br>Priest XXX, Rector of the Basilica of Our Lady of Monterrey.<br><br>Immersion 2: Visit only students for integration as work teams, assimilation of knowledge, interaction with spaces, objects of study and people involved in these spaces.<br><br>Master class, 3/6:<br><br>4. XXX: BA in History from the Faculty of Philosophy and Letters of UNAM, master and PhD candidate in Mesoamerican Studies 2.<br><br>5. XXX, Dr. in Hispanic Letters, Lic. in Hispanic Letters Ex A Tec, and expert in paleontology and researcher and promoter of Digital Humanities. Project advisor<br><br>6.XXX, B.A. in Communication Sciences ExATec 2003, and M.A. in Humanistic Studies. Co-editor and content generator in the communication media of Campus Monterrey Conecta (https://conecta.tec.mx/es) and other institutional channels. | Counseling and guidance to the group of students throughout these weeks in and out of the classroom.<br><br>Pre-production<br><br>Production<br><br>Post-production<br><br>Project presentation: nine multiplatform productions.<br><br>Post test application. |

The results includes the following 9 multimedia productions developed by 9 teams for the Training Partner:

1. 360 Virtual Tour - Basilica of Our Lady of Monterrey. https://roundme.com/tour/867808/view/2719367/
2. Virtual catalog of the exhibition Costuras del cielo: El ajuar de la Virgen del Roble.
3. https://www.canva.com/design/DAFCxoOiulY/jQbfJiUVxhdehR4rB9bL3g/view?utm_content=DAFCxoOiulY&utm_campaign=designshare&utm_medium=link2&utm_source=sharebutton
4. Animation of the history of the Virgin of Monterrey. Duration 4.33. https://youtu.be/G7SKfxvfsCk
5. Electronic page - Catalog of works of the Archdiocesan Museum of Sacred Art. https://a011777515.wixsite.com/website
6. Documentary Basilica of Our Lady of Monterrey. Duration 2.49. https://www.youtube.com/watch?v=7Ih2gNTCJQ0
7. Documentary of the Archdiocesan Museum of Sacred Art. Duration 13.02 minutes. https://youtu.be/lbdCLjAslxY
8. History of the Virgin of Monterrey. Duration 3.23 minutes https://www.youtube.com/watch?v=_U62Rzbp5Lg&list=LL&index=3&t=7s
9. The dresses of the Virgin of Monterrey. Duration 6.31. https://www.youtube.com/watch?v=jEclQEN-7uk&list=LL&index=2
10. Documentary on the Basilica of Our Lady of Monterrey. Duration 3.23 seconds. https://www.youtube.com/watch?v=X0AimxhkEc4&list=LL&index=1

## 4. Results evaluation

The initial research assumption: "Students will develop to a greater extent the transversal competencies integrated to their curriculum by applying technology to recover and promote the cultural heritage of the city" was favorably verified with the instrument measuring the development of transversal competencies (Olivares, 2018). The values were in a range from 1: totally disagree, to 5: totally agree. 40 students applied the pre-test and 20 the post-test; to analyze the results, those who answered it at both moments, before and after, were identified: they were 16 students.

Results analysis process:

a. Pres test: in each question the accumulated points of the answers with 4 and 5 frequencies were added up.
b. Post test: in each question, the accumulated points of the answers with 4 and 5 frequencies of the same question were added.
c. Comparative: the before and after of the accumulated points were compared.
d. Analysis of results.

From the beginning of the course, high expectations were reflected in all aspects, since answers with 4 and 5 in all of them added up to +10/16 frequencies.

In all the questions, the number of frequencies with 4 and 5 points of the pre-test was surpassed, to be reflected in the higher number of frequencies with 4 and 5 points of the post-test.

Comprehensively, the transversal competencies had a higher number in the post-test: (1) Intellectual curiosity +3; (2) Use of technology +4; (3) Professional impact +5.

The level of expectations for the course was maintained and exceeded and was reflected in the level of commitment of the students to the solution of the challenges agreed upon at the beginning of the semester.

Table 3. Comparative pre-test and post-test of the instrument for measuring the development of transversal competencies by question and a general one.

| | 1 | 2 | 3 | 4 | 5 | Result: sum of answers with 4 and 5 | Difference pre / post |
|---|---|---|---|---|---|---|---|
| **1. Intellectual curiosity Pre test** | **0** | **3** | **2** | **11** | **0** | **11** | **-** |
| **1. Intellectual curiosity Post test** | **0** | **0** | **2** | **6** | **8** | **14** | **+3** |
| Pre - I expect the selected activity to challenge me intellectually | 0 | 1 | 1 | 5 | 9 | 14 | - |
| Post - The activity challenged me intellectually. | 0 | 0 | 0 | 6 | 10 | 16 | +2 |
| Pre - I expect to solve problems relevant to my professional development during the immersion semester. | 1 | 0 | 0 | 2 | 13 | 15 | - |
| Post - I solved problems relevant to my professional development. | 0 | 0 | 0 | 3 | 13 | 15 | +1 |
| Pre - I spend time searching for information to learn new topics. | 0 | 2 | 1 | 4 | 9 | 13 | - |
| Post - I spent time searching for information to learn about the topic related to the activity. | 0 | 0 | 1 | 2 | 13 | 15 | +2 |
| **2. Use of Technology Pres test** | **0** | **0** | **6** | **8** | **2** | **10** | **-** |
| **2. Use of Technology Post test** | **0** | **0** | **0** | **13** | **3** | **16** | **+4** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Pre - I expect to make use of technology in challenging activities. | 0 | 0 | 1 | 0 | 15 | 15 | - |
| Post - I had the opportunity to make use of technology in the challenging activity. | 0 | 0 | 0 | 3 | 13 | 16 | +1 |
| Pre - Time and resources are used efficiently in the projects. | 0 | 2 | 2 | 5 | 6 | 11 | - |
| Post - Time and resources were used efficiently. | 0 | 0 | 0 | 6 | 10 | 16 | +5 |
| Pre - I developed creative solutions to complex problems. | 0 | 0 | 2 | 3 | 11 | 14 | - |
| Post - I developed creative solutions to challenging activities in this immersive semester. | 0 | 0 | 0 | 4 | 12 | 16 | +2 |
| **3. Professional impact Pre test** | **0** | **2** | **4** | **3** | **7** | **10** | **-** |
| **3. Professional impact Post test** | **0** | **0** | **1** | **3** | **12** | **15** | **+5** |
| Pre - The organizations I have been involved with have benefited from my actions. | 0 | 2 | 4 | 3 | 7 | 10 | - |
| Post - The organization we participated with benefited from our actions. | 0 | 0 | 1 | 3 | 12 | 15 | +5 |

ECOA. In the institutional student feedback survey on the subject (ECOA), the result was 9.28/10, and with comments from the students written voluntarily gratifying about this experience and very encouraging for the teaching team.

The training partner declared his satisfaction with the productions:

> June 30, 2022
> "Dear professor Gerardo:
> I am surprised by the excellent work that the Tec students did, from me they all have a 100 for their effort, dedication and creativity and I thank them for collaborating with me on this project. I hope that in the future we can continue working on something as valuable as our history, that of the city and that of the Virgen del Roble
> I remain infinitely grateful and at your service in Christ.
> Rector XXX, Basilica of Our Lady of the Roble. Monterrey, Mexico."

Spontaneous student testimony:

> May 13, 2022
> "Thank you for everything taught during the course, teacher. We take more than class information with us. It inspires us to continue creating in our own way, without forgetting our roots and the works of generations who were looking for the same thing as us... a space in this [world] to shine." Andrés XXX, student."

Additionally, it is interesting to note that a grandmother, four mothers, a brother and four friends joined the visits with the students.

## 5. Conclusions

The general objective of the research and the five specific objectives presented at the beginning of this work were achieved, thus validating, and consolidating the didactic design and implementation of this educational innovation. In all educational innovation and research, measurement instruments are essential to validate the results of the teaching/learning process and the development of competencies. It is suggested to replicate it with more groups of engineering students in more universities to join projects of recovery, rescue and dissemination of historical, artistic and cultural heritage of a city, region or community from all professions. Interdisciplinarity is important for the safeguarding of cultural heritage, both for the personal and professional formation of the student, as well as for the current society in Mexico. The competencies must be very well related in the formation of people to detonate the commitment with the recovery, rescue and promotion of cultural heritage, as well as with the encounter of a personal identity from an approach of the "I in search of meaning" and thus move to the approach of "The encounter with the cultural other”. Following this research, the didactic model has been implemented with six additional groups and four different training partners.

It is important to consolidate this educational innovation project as an imprint for the memory, preservation and dissemination of our artistic legacy and respect for its proponents; as a sign that guides the current artistic inspiration as a source of cultural identity for a comprehensive community development; and a symbol of union between artists and cultural promoters of several centuries with a common purpose: to identify the region as an international artistic reference. In this 21st century, it is up to us to attend to their commission; and to continue preserving, cultivating and strengthening this valuable legacy; replicating this model in many cities is an opportune educational alternative for this noble purpose to overcome uncertainty: to build bridges between society and learning in the future. In future research we will request the application of the necessary pre-test and post-test instrument of the course and achieve an investigation.

The Novus Educational Innovation Project - Tec de Monterrey (2023) experience is shared in Spanish in the following video, developed by Gerardo González Lara, Carolina Sacristán Ramírez: https://www.youtube.com/watch?v=bCvyJ3wZYEI

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# PAEE/ALE’2024 Full Papers – Students’ Award Submissions

Submissions accepted for the PAEE/ALE’2024 Students’ Award.

# Project-Based Learning in Engineering Education: A Systematic Review of the Literature

Soraia Stabach Ribas Ferrari dos Santos[1], Luis Maurício Martins de Resende[2], Juliana Castanon Xavier[3]

[1] PhD student in Science and Technology Teaching - Federal Technological University of Paraná - UTFPR
[2] PhD in Mechanical Engineering from the Federal University of Santa Catarina, Professor of the Graduate Program in Science and Technology Teaching – UTFPR
[3] PhD in Computer Science from the Federal University of Rio de Janeiro – UFRJ, Professor at UTFPR. Campos Apucarana.

Email: soraiasr@hotmail.com, lmresende@utfpr.edu.br, julianaxavier@utfpr.edu.br

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**Abstract**

Project-based learning (PBL) has been widely recognized as an effective approach in engineering education, allowing students to apply theoretical concepts to real projects. This systematic review of the literature seeks to examine the benefits and challenges of PBL in engineering education, based on a systematic review of the literature. The methodology adopted included the careful selection of descriptors and databases, followed by a process of filtering and analysis of the articles obtained. Of the 43 articles selected, the results reveal a growing number of publications on the subject over the years, reflecting ABP's continued interest and relevance in engineering. The most relevant journals were identified, highlighting the transversality of PBL in the different areas of engineering. In addition, five key studies have been compiled that highlight the benefits of PBL, such as increased student engagement and the development of essential skills. However, challenges such as additional workload and complexity in the assessment have also been identified. Therefore, strategies to overcome these limitations are needed to maximize the benefits of PBL. A possible future direction would be the adoption of an Innovative Teaching Methodology that connects students to the job market, allowing them to apply their knowledge in real contexts under the supervision of professionals in the field. This approach would not only enrich the educational experience but also prepare students more effectively for professional challenges.

**Keywords**: engineering education, benefits and challenges, innovative teaching methodology.

## 1 Introduction

Project-based learning (PBL) has been recognized as an effective approach to teaching and learning in diverse educational contexts, including engineering education. PBL involves the exploration of theoretical concepts through practical application in real or simulated projects, allowing students to develop technical, cognitive, and socio-emotional skills that are essential for their professional training (OLIVEIRA; SEE; ROME, 2020). In the context of engineering education, PBL has been widely adopted as a strategy to engage students, promote meaningful learning, and prepare them for industry challenges.

This systematic review of the literature aims to examine the main benefits and challenges associated with the implementation of PBL in engineering education. To this end, a set of scientific articles that address this theme and present studies and experiences related to the application of PBL in engineering courses will be analyzed.

Articles published in scientific journals that address aspects such as the design and implementation of project-based courses, pedagogical strategies used and results will be considered. Information will be collected on the contexts in which PBL was applied, the types of projects developed, the assessment methods used and the results achieved in terms of student learning.

The methodology used for the selection of articles, data extraction and analysis of results is described below. The main findings of the review and their implications for educational practice are presented below. Finally, the limitations of the study will be discussed and possible directions for future research in the area of PBL in engineering education will be identified.

## 2 Method

The method used in this study was a systematic review of the literature, which involved nine steps based on the Methodi Ordinatio (Pagani *et al.*, 2022; Heathen; Kovaleski; Resende, 2015). The measures adopted were as follows:

1) Stage - Establishment of search intent:

At this stage, the relevant descriptors were identified and the most appropriate combinations were made to answer the research question: "What are the main benefits and challenges associated with the implementation of PBL in engineering education?"

- Descriptors: Project-Based Learning - Engineering Education
- Time horizon: (between 2013 and 2023) - 10 years
- Peer-reviewed articles only.

2) Stage - Exploratory search with the descriptors in the databases:

The descriptors and combinations identified in step 1 were tested in the Web of Science, Scopus, Science Direct, IEEE Xplore and ACM Digital Library databases.

Specific descriptors were used to search for articles, such as "Project-Based Learning" AND ("Engineering Education" OR "Engineering Education"), covering a 10-year time horizon, from 2013 to 2023. Additionally, we restrict our search to peer-reviewed articles, ensuring that only high-quality work is included.

3) Stage - Definition of the combination of descriptors and databases to be used:

The databases selected in Stage 2 were considered adequate, as they presented a significant number of relevant publications related to the descriptors researched, in addition to wide availability of access to the published materials.

4) Stage - Definitive search in the databases

The most representative databases in the international literature were selected for search, as described in Table 1, using the descriptors explained therein, over a period of ten years. The results of the searches in each database can also be seen in Table 1.

Table 1. Database search results

| TERMS | WEB OF SCIENCE | SCOPUS | DIRECT SCIENCE | IEEE XPLORE | ACM DIGITAL LIBRARY |
|---|---|---|---|---|---|
| "Project-Based Learning" AND ("Engineering Education" OR "Engineering Education"). | 30 | 244 | 444 | 174 | 253 |

From the total of 1145 articles found, and with the help of the Mendeley software, the following steps were taken.

5) Internship - Filtration Procedures

In the current stage, duplicate papers, papers presented at conferences that do not have an impact factor, books or book chapters, and those that did not adhere to the theme of the present study were eliminated, with the aim of further refining the selection of articles for analysis.

At this stage, the removal of duplicates was performed using the Mendeley software, which facilitated the efficient management of references. Then, we read the keywords and abstracts of each article in detail. Those that did not directly address engineering education were excluded, ensuring that only studies pertinent to the central theme were considered. This critical step ensured the inclusion of highly relevant literature for our analysis, as shown in Table 2.

Table 2. Filtering Procedures

| | |
|---|---|
| Duplicate roles excluded: | 264 |
| Papers presented at conferences that do not have an impact factor, books or book chapters | 545 |
| Deletion of off-topic articles: | 498 |
| Total articles excluded: | 779 |
| Number of resulting articles in the portfolio: | 47 |

Exclusion criteria included the elimination of publications such as conference papers, books, and book chapters, focusing exclusively on peer-reviewed journal articles. Adherence to the central theme was determined through careful analysis of abstracts and keywords, ensuring that each selected paper contributed significantly to the understanding of the benefits and challenges of Project-Based Learning in engineering education.

6) Stage - Identification of the impact factor, the year of publication and the number of citations

At this stage, the JCR of the journal where each of the articles was published was surveyed, as well as the number of citations of each one, in order to classify the articles, as proposed by the methodology used.

7) Stage - Classification of articles through InOrdinatio;

The classification of the articles was based on the calculation of the InOrdinatio of each article, based on the following equation (Pagani, Kovaleski, & Resende, 2015):

$InOrdinatio = (Fi / 1000) + (\alpha*(10 - (ResearchYear - PubYear))) + (\sum Ci)$

Where: Fi = Journal impact factor;

α* = coefficient attributed by the researcher to the relevance of the year of publication, which can range from 1 to 10;

AnoPesq – Year of search in the databases;

PubYear = year of publication of the article;

∑ Ci = number of citations in the article.

In the survey, the value attributed to α was 10, considering that the timeliness of the articles is paramount.

8) Stage - Location of the articles in full

The location of the articles was done directly on the journal's website through the CAPES Journal Portal, with access to CAFe.

9) Stage - Reading and systematic analysis of the articles

After reading, four articles that did not contain elements to answer the research question were also excluded. To avoid saturation, the composition of the documentary corpus was limited to positive results in the InOrdinatio equation.

# 3 Findings

Figure 1 shows the distribution of the analyzed articles according to the year of publication, showing an increase in interest in the topic in the last five years.

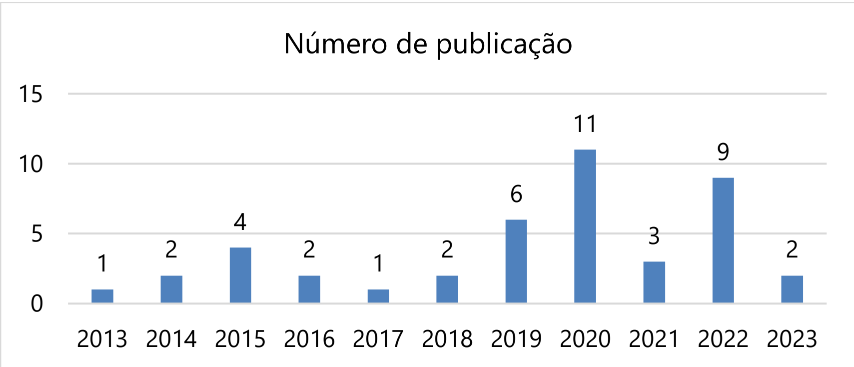


Figure 1. Number of articles published on the topic over the years.

Figure 2 shows the most relevant journals on the topic of PBL in engineering education, considering the impact factor and the number of publications. The analysis of this graph allows us to identify the journals that are most dedicated to the topic, in addition to providing insights into the quality and scope of the research published.

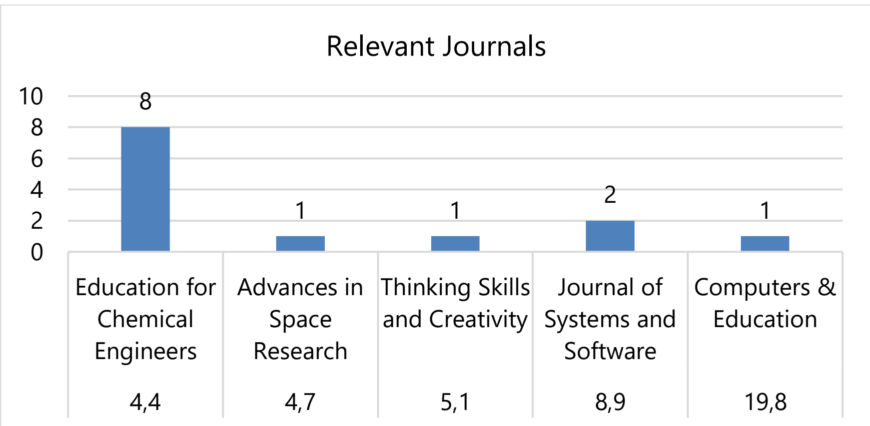


Figure 2. Main journals of relevance.

The dispersion of journals in different areas of knowledge demonstrates the transversality of PBL, which can be applied in several areas of engineering. The presence of high-impact journals indicates that research on PBL in engineering education has been gaining recognition and quality. The relatively low number of publications in each journal suggests that PBL is still a developing research area with potential for future growth.

After reviewing the articles, the five main works were compiled that offer pertinent information for understanding the benefits and challenges of implementing PBL in engineering education. Table 3 summarizes the main characteristics of these studies.

Table 3. Main Articles on PBL in Engineering Education

| ITEM NAME | AUTHORS | YEAR | GOAL | AREA OF APPLICATION | METHODOLOGY | FINDINGS |
|---|---|---|---|---|---|---|
| Additive Manufacturing: An Education Strategy for Engineering Students | A. Stern, Y. Rosenthal, N. Dresler, D. Ashkenazi | 2019 | Introduce an additive manufacturing course for engineering students | Engineering Education | Development of engineering projects using additive manufacturing | The engineering projects served as a useful learning experience, encouraging students' creativity and motivation |
| Proposal of a method of evaluation of individual contributions using the function point in the implementation phase in project-based learning software development | K. Tanabata, A. Hazeyama, Y. Yamada, K. Furukawa | 2021 | Propose a method of evaluation of individual contributions in the implementation phase in learning projects based on software development projects | Software Development Education | Using the Function Point Method to Evaluate Individual Contributions | Proposed method allows fair evaluation of individual contributions in software development projects |
| Combining Traditional Teaching Methods and PBL for Lean Manufacturing Teaching and Learning | G. Tortorella, P. Cauchick-Miguel | 2018 | Integrate traditional teaching methods and PBL into lean manufacturing teaching and learning | Lean Manufacturing Education | Traditional teaching approach combined with PBL | PBL can be an effective and complementary method for learning lean manufacturing |
| Applying project-based learning and SCAMPER teaching strategies in engineering education to explore the influence of creativity on cognition, personal motivation, and personality traits | T.T. Wu, Y.T. Wu | 2020 | Apply project-based learning and SCAMPER teaching strategies in engineering education to explore the influence of creativity on cognition, personal motivation, and personality traits | Engineering Education | Application of SCAMPER project-based teaching and learning strategies | Differences between students with high and low creativity in terms of cognition, personal motivation, and personality traits |

## 4 Discussion

Table 4 shows the main benefits of using PBL, as discussed in the articles analyzed.

Table 4. Benefits of PBL in Engineering Education evidenced in the Articles.

| BENEFIT | EVIDENCE IN THE ARTICLES |
|---|---|
| Increased student engagement | **Stern *et al.* (2019):** Engineering projects motivated and engaged students.<br>**Wu & Hyatt (2016):** Active learning and student engagement in the construction of solar houses. |
| Development of Core Competencies | **Stern *et al.* (2019):** Engineering projects fostered creativity and problem-solving.<br>**Tanabata *et al.* (2021):** Development of teamwork skills in software projects.<br>**Wu (2020):** Influence of creativity on cognition, motivation, and personality. |
| Active and Contextualized Learning | **Stern *et al.* (2019):** Application of knowledge in real projects.<br>**Tortorella & Cauchick-Miguel (2018):** PBL as a complementary method for learning lean manufacturing. |
| Better Preparation for the Job Market | **Wu & Wu (2020):** Developing skills relevant to the labour market. |

In summary, the studies reported in table 4 suggest that PBL not only improves student learning, but also better prepares them for the job market and the real world (GONZALEZ, ALVARADO, PEÑA, 2017), promoting the development of essential skills and providing a more engaging and relevant learning experience. These findings highlight the importance of PBL as an effective pedagogical approach in engineering education.

PBL emerges as a dynamic educational approach, enabling the student to apply theoretical knowledge in real situations. This integration between theory and practice, as Fernandes (2017) points out, not only deepens the understanding of the concepts studied, but also cultivates essential skills for the professional world. In addition, by facing real challenges, students are led to explore creative and innovative solutions, stimulating not only critical thinking but also the ability to generate original ideas to solve complex problems, as highlighted by Gonzalez, Alvarado, and Peña (2017).

Collaborative interaction between students from different fields is another crucial facet of PBL, which promotes interdisciplinarity and the development of fundamental interpersonal skills. As Fernandes (2017) points out, this collaboration promotes the strengthening of teamwork, improves effective communication, and enables students to consider diverse perspectives, preparing them for the plurality of professional environments. In addition, by actively participating in the design and execution of challenging projects, students become protagonists of their own learning journey, which not only motivates and engages them, but also contributes significantly to their academic and personal development, as noted by Esteban and Arahal (2015).

Table 5 describes the main challenges cited by the articles analyzed

Table 5. Challenges of PBL in Engineering Education listed in the Articles

| CHALLENGE | EVIDENCE IN THE ARTICLES |
|---|---|
| Additional workload for students and teachers | **Stern *et al.* (2019):** Engineering projects may require more time and effort from students. |
| Need for training and support | **Stern *et al.*** (2019): Teachers may need training to implement PBL. |
| Complex Valuation | **Tanabata *et al.*** (2021): Difficulty in evaluating individual contributions in software projects. |

In this analysis, we will examine, according to table 5, the main PBLs, which summarize the challenges encountered in the implementation of PBL in different educational contexts. The goal is to better understand these barriers and seek strategies to overcome them, aiming to maximize the benefits of this pedagogical approach.

Coordination and organization are significant challenges in the implementation of PBL, requiring careful structuring on the part of both teachers and students. Setting clear objectives, establishing development steps, and creating evaluation criteria are all essential steps for the success of projects. Additionally, it is critical to ensure that the necessary resources are readily available and that project teams are properly trained and monitored throughout the process, as highlighted by Cifrian *et al*. (2020).

Fair and objective evaluation represents another challenge in PBL, as highlighted by Colim *et al.* (2022). The analysis of projects in this context involves the consideration of various aspects, including individual student performance, team collaboration, and the results achieved. To address this challenge, it is essential to develop transparent and objective evaluation criteria, covering both the technical and non-technical aspects developed during the project. This approach promotes a comprehensive assessment that recognizes the complexity and diversity of skills acquired by learners throughout the project-based learning process.

# 5 Conclusion

PBL has been shown to be an effective pedagogical approach in engineering education, as indicated by the reviewed studies. The highlighted benefits underscore its importance in improving student learning and preparing for the job market by promoting engagement, skills development, and a more meaningful learning experience.

However, the implementation of PBL presents challenges, including additional workload, the need for teacher training, and complexity in assessment, especially in software projects. To overcome these limitations and advance research, it is important to investigate strategies to reduce workload, increase faculty support, and develop more effective assessment methods.

A possible future direction would be the adoption of an Innovative Teaching Methodology that connects students to the job market. This could be accomplished through a transdisciplinary project development lab, allowing students to apply their knowledge in real-world contexts, under the supervision of professionals in the field. This approach would not only enrich the educational experience but also prepare students more effectively for professional challenges

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# KPIs to Measure Impact of Technology Projects in the UN 2030 Education Agenda

Gabriel de Lanna Fiuza Curi Garcia[1], Luis Guilherme Borges Monteiro[2], Luiz Henrique Fernandes Zamprogno[2], Simone Borges Simão Monteiro[1], Dianne Magalhães Viana[3], Edgard Costa Oliveira[1], Ana Cristina Fernandes Lima[1]

[1] Production Engineering Dept., Faculty of Technology, University of Brasília, Brasília, Brazil
[2] Software Engineering, Campus Gama, University of Brasília, Brasília, Brazil
[3] Mechanical Engineering Dept., Faculty of Technology, University of Brasília, Brasília, Brazil

Email: gabriel.lanna@aluno.unb.br: 211045178@aluno.unb.br, 190033681@aluno.unb.br; simoneborges@unb.br; diannemv@unb.br; ecosta@unb.br; anacristina.limafernandes@gmail.com

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**Abstract**

The development of projects in engineering education often faces the challenge of accurately measuring their impact, particularly in social development. This article introduces a set of KPIs designed to overcome this challenge, which will allow data collection via indicators and the proposal of views to monitor the impact and performance of project solutions on organizations. The study is based on a sample of three projects that took place at UnB, Brasília, in the realm of international cooperation and aiming towards the United Nations 2030 Agenda. The research process consists of three phases: identifying indicators to measure the impact of projects on global societies, determining the necessary data requirements for the indicators, and creating a dashboard to showcase project impact results. This research will help provide data for future projects to be carried out through the Project-Based Learning (PjBL) methodology and in the context of the UN SDG- sustainable development goals. The tool will be integrated into the Unified Platform for Active Methodologies (PUMA), a project conducted at UnB, aimed at evaluating and improving the PjBL methodology within engineering course projects.

**Keywords**: 2030 Agenda; Project Based Learning; Indicators; Impact of Social Results.

## 1 Introduction

From the United Nations 2030 Agenda, a global action plan to eradicate poverty through sustainable development, it is possible to explore the role that educational projects in engineering can play in aligning with these global goals. This proposal gains importance with the UNESCO guideline (2019) on Education for Sustainable Development (ESD), which aims to empower students with the knowledge, skills, values, and attitudes necessary to make informed choices and act responsibly in environmental, economic, and social contexts. However, as highlighted by Neves et al. (2024, p. 163), "to promote a better understanding of sustainability issues, ESD needs to incorporate methods that foster critical thinking, problem-solving, and active student participation".

Thus, Problem-based Learning (PBL) and Project-based Learning (PjBL) have emerged as effective methods that transcend traditional education, promoting more interactive and practical learning. Studies show that these methods not only improve students' academic outcomes but also equip them with skills to solve complex problems and make effective decisions in real professional environments (Powell; Weenk, 2003; Savin; Howell, 2004; Graaff; Kolmos, 2007; Chen and Du, 2021).

However, as ESD is integrated into engineering curricula, one of the main challenges in implementing these approaches is the accurate assessment of projects' impacts. The complexity of quantifying social outcomes demands innovative tools that can collect and analyse data effectively. KPI dashboards are a promising tool that allows detailed monitoring of the performance and impact of projects both in the training of engineering students, and in professional use in organizations in general.

The aim of this work is to develop and implement indicators that can measure the impact of engineering education projects on society, based on active learning approaches, as PBL, and by using a sample of projects conducted at the University of Brasília. This tool aims to provide a database that can be used to continuously improve educational projects in line with the United Nations Sustainable Development Goals (SDGs).

This paper is organized as follows: initially, a theoretical background and the methodology used to develop the impact indicators are presented. Then, examples of these indicators' application are provided. Through this proposal, it is possible to offer a view of how engineering education projects can be aligned with the principles of sustainable development from the 2030 Agenda.

# 2 Background

This section introduces theoretical concepts that underpin the research.

## 2.1 PBL Approaches

According to Šmitiņa and Margeviča-Grīnberga (2021), students prefer active, interactive teaching and learning methods which require active engagement, responsibility, problem-solving, decision-making, and self-assessment. Additionally, as noted by AbdelSattar & Labib (2019), active learning has several advantages in engineering education. For instance, it enhances student outcomes compared to traditional methods, their ability to solve open-ended problems, and their general knowledge.

As asserted by Chen and Du (2021), Problem-Based Learning (PBL) constitutes an active learning approach wherein students collaborate in small groups to solve open-ended, real-life problems through self-directed learning. The authors highlight PBL's widespread adoption in engineering education owing to its anticipated advantages in enhancing students' academic performance and transferable skills. Among the benefits of implementing PBL in engineering education is its effectiveness in preparing students to address real-world workplace challenges.

As indicated by Sukackė et al. (2022), active learning strategies, such as Project-Based Learning (PjBL), emerge as among the most pertinent and extensively researched approaches for enhancing learning in engineering. PjBL learning environments are characterized by the fundamental principle of engaging students in solving open problems with an interdisciplinary nature, typically within team settings. A key objective of PjBL is the creation of a final product, distinguishing it from other methods. PjBL often shares commonalities with problem-based learning, as both strategies emphasize collaboration and self-direction. However, the primary distinction lies in the fact that PjBL activities more closely resemble professional tasks.

## 2.2 Sustainability in Projects

The concept of sustainability is related to a process of transformation in which the use of resources, investment allocation, technological development direction, and institutional changes are aligned with both present and future requirements, according to Khalifeh, Farrell & Al-edenat (2020).

Sustainability comprises three pillars, as shown in Figure 1, the environmental, economic, and social pillars known as the triple bottom line (TBL).

Laedre, Haavaldsen, Bohne, Kallaos & Lohne (2015) recommend that when an investment project is evaluated in terms of sustainability, it should involve assessing its impact on the three pillars: environmental, economic, and social.

By ensuring good practices in indicator development, consulting users may select appropriate indicators. Regular updates and reporting of these indicators offer clear signals regarding the success or failure of national policy initiatives and actions, as mentioned by Dahl (2012).

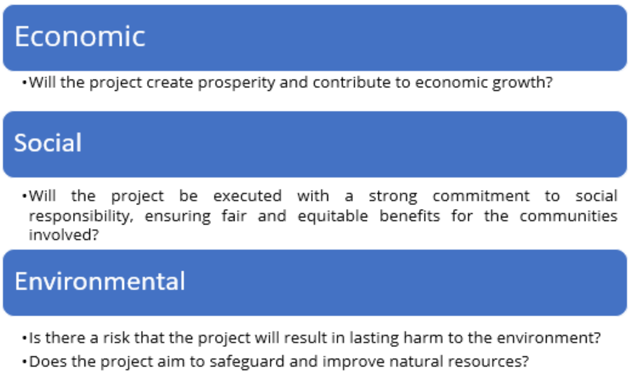


Figure 1. Key questions of the pillars of sustainability. (Adapted from Keeble, Topiol & Berkeley, 2003)

Indicators must align with the business realities, values, and culture of the organization. Therefore, their development should not be restricted to predefined methodologies or standards (Keeble, Topiol & Berkeley, 2003). These authors suggest a method for evaluating performance at operational levels, such as among projects themselves, where direct environmental, social, and economic impacts are observed. They exemplify this approach with a case study showcasing how businesses can create a suitable set of indicators at two specific levels within the organization: the corporate level and the project level.

To measure a project's impact, it is important to understand which indicators are more suitable for the organization's context. For example, at a corporate level, social responsibility is needed to deliver "sustainable economic, environmental, and social value to organization's extended stakeholders and society in general" (Fonseca et al, 2021). Plenty of social impact and sustainability indicators were created to track, analyze, and certify projects and organizations. Business Corporate certification, for example, is based on a Business Impact Assessment (BIA) to measure and manage a company's positive impact on its workers, community, customers, and environment, both at the operational and business model levels. The assessment covers 5 main aspects of an organization, as shown in Table 1.

Table 1. Impact Assessment general criteria.

| **Criteria** | **Main Topics** |
|---|---|
| Governance | Adoption of a social or environmental mission, ethics, accountability, and transparency<br>Engagement with employees, board members, community, and customers<br>Diversity of governing bodies |
| Workers | Compensation, benefits, training, and ownership opportunities<br>Work environment, communication, health and safety, career development and job flexibility<br>Worker ownership and engagement |
| Community | Supplier relations, diversity, and involvement in the local community, for example, community service and charitable giving<br>Whether a company's product or service is designed to solve a social issue |

| | |
|---|---|
| Environment | Environmental management, products, and services<br>Emissions, water, waste<br>Resource preservation<br>Energy efficiency<br>Suppliers and transportation<br>Impacts on climate, water, land, and life<br>Whether a company's products or services are designed to solve an environmental issue |
| Customers | Company impact on its customers, namely whether its products or services promote public benefit and if those products/services are targeted towards serving underserved populations<br>Whether a company's product or service is designed to solve a social or environmental issue |

Adapted from Fonseca et al (2021)

Regarding the PBL methodology in project disciplines, it is difficult to implement it successfully because "learners often lack the self-regulation skills required to monitor, reflect, manage and assess their project activities and learning. Furthermore, most learning systems rarely offer possibilities to monitor and reflect on their project and learning processes." (Michel et al, 2017). However, there are possible indicators to measure the success of PBL approaches from different perspectives. Traverso-Ribón et al (2016), for example, propose a set of 3 criteria for learning assessment in a PBL experience: the balanced allocation of tasks to the different project roles (C1), the use of tools of the software forge (C2) and the accomplishment of tasks and milestones on time (C3). Table 2 shows which metrics were used to assess each criterion.

Table 2. Metrics used for each criterion.

| **Criteria** | **Metrics** | **Description** |
|---|---|---|
| C1 | Teamwork balance<br>Leadership<br>Resolutive capability | Standard deviation of number of tickets assigned to each team member<br>User who created more tickets<br>User who solved more tickets |
| C2 | Planning creations<br>Planning updates<br>Version control | Maximum number of days between consecutive ticket creations<br>Maximum number of days between consecutive ticket updates<br>Maximum number of days between consecutive commits |
| C3 | Deadline fulfillment | Average delay in the completion of milestones |

Adapted from Traverso-Ribón et al (2016)

Michel et al (2017), on the other hand, propose not a set of indicators for PBL projects, but a platform that helps students to manage their activities, in which they can create and manage customizable indicators. A personalized dashboard is then generated, so students and teachers can easily track the projects' progress and evaluate what's relevant to them. It is important that the platform provides a guideline for the creation of indicators, to assure that they are S.M.A.R.T. (Specific, Measurable, Attainable, Relevant, and Timely). Dashboards are a visual way to analyze data and indicators and can be built into different software, such as Microsoft Excel/Google Sheets, Power BI, Looker Studio, Tableau, etc. But they have to be built strategically, otherwise they may not be useful. According to Michael K. Allio (2012), "a strategic dashboard is one that homes in on the key metrics that reflect progress in implementing strategy. Its primary value lies in its ability to focus senior executive attention, provoke analysis and reflection, and trigger decision-making that improves performance." The author has created a requirements checklist for a good dashboard, as seen in Table 3.

Table 3. Strategic Dashboard Checklist.

| **Dimension** | **Description** |
|---|---|
| Metrics | Indicators/metrics are tightly aligned with strategy, prioritized, and balanced |
| Audience | It is clear to the whole organization who the dashboard is designed for, and how it's used |
| Data Capacity | Data collection, infrastructure, analysis, and management are well-developed/organized |
| Stakeholders | Involved key staff and stakeholders in metrics design & progress reporting |
| Design | Succinct, accessible display; management judgment was included |

| | |
|---|---|
| Process | There is a formalized key dashboard process: when it's updated, presented, modified |
| Accountability | The responsibility for managing dashboard content and processes was assigned to one or more members |
| Effectiveness | Members of the organization used the dashboard to trigger strategic analysis, discussion, and decision-making |

Adapted from Allio (2012)

For projects aiming towards the United Nations 2030 Agenda, it is crucial to analyze their impacts, especially on the lens of sustainability indicators.

## 2.3 Sustainability Impact Indicators of Projects

The questions that underlie the pillars of sustainability, triple bottom line (TBL), are described in Figure 1.

The sustainability indicators of projects can be assessed on a scale of 1 to 5, where a score 1 indicates weak alignment with the principles of sustainable development, and a score 5 indicates strong alignment with the principles of sustainable development. Here are three categories of indicators extracted from the literature (Table 4).

Table 4. Sustainability indicators according to pillars of sustainability.

| **Economic Sustainability Indicators (ESI)** |
|---|
| ROI (Return on Investment) |
| Financial benefits arising from environmental and social practice |
| Impact on the local economy |
| **Social Sustainability Indicators (SSI)** |
| SROI (Social Return on Investment) |
| Number of benefited communities |
| Number of actions that benefit society |
| **Environmental Sustainability Indicators (EnSI)** |
| Percentage of projects that generate results in eco-efficiency |
| Percentage of projects that generate results in energy efficiency |
| Percentage of projects that focus on renewable energy sources |
| Percentage of projects that aim to reduce the use of natural resources |
| Percentage of projects that use Recycling and Reuse of products |
| Percentage of projects that focus on reverse logistics |

Adapted from Topiol & Berkeley (2003); Stanitsas & Leopoulos (2021)

These guidelines will be useful for the creation of projects KPIs proposed in this article.

# 3 Methodology

This research takes an applied approach, aiming to propose indicators for assessing the initiatives of sustainability projects and their impact on society. It employs an exploratory method, sourcing proposed indicators from existing literature for data compilation. Moreover, it has a qualitative focus, prioritizing the presentation of a prototype of indicators for impact assessment rather than variable measurement.

The study’s framework comprises three stages. Firstly, it involves identifying indicators to measure the impact of projects on sustainability, aligning with the SDGs. Subsequently, the second stage entails the development of a form for assessing these indicators, while the final stage focuses on creating a prototype that illustrates the project’s adherence to sustainability principles.

## 4 Indicators for International Sustainability Projects

The literature review on sustainable project indicators supported the proposal of indicators for the creation of a dashboard that can be used in the evaluation of projects within the context of an international partnership. This partnership takes place among two universities: the University of Brasília, Brazil and Aalborg University, Denmark. Each semester, an international event called SDG Challenge is held, involving professors and students from each institution. The outcome of this event is a project plan to be executed throughout the semester, focusing on solid waste management and recyclable materials cooperatives. With the project plan and the definition of the scope of each discipline, each partner university develops the project with its students. The question arises: How can the impact of the results of each of the projects developed by the students be assessed? To address this question, a set of indicators is proposed that can be measured based on the results of the deliverables. Table 5 presents the indicators.

Table 5. Sustainability Indicators for the SDG Challenge Project Portfolio.

| Indicators | Description | Calculation measures |
|---|---|---|
| **1. Project Key Management Indicators (PKMI)** | | |
| 1.1 Scope compliance index | How well the solution delivered represented what was planned | % of actual deliveries vs. planned deliveries |
| 1.2 Technical feasibility of the proposed solution | Validation of stakeholders regarding the proposed solution | Score from 0 to 100% |
| 1.3 Solution applicability index | How applicable the delivered solution proved to be | Score from 0 to 100% |
| **2. Learning Indicators (LI)** | | |
| 2.1 Student engagement index | How engaged the student was with the project | Score from 0 to 100% |
| 2.2 Learning level | Student evolution in technical and transversal skills | Score from 0 to 100% |
| **3. Economic Sustainability Indicators (ESI)** | | |
| 3.1 VPL - NPV | Net present value | R$ |
| 3.2 TIR | Internal Rate of Return | % per year |
| 3.3 Payback | Return on investment | Time (years and months) |
| **4. Social Sustainability Indicators (SSI)** | | |
| 4.1 Index of benefited waste pickers | Number of waste pickers benefited by the project | Number |
| 4.2 Satisfaction index with the solution | Collectors' satisfaction with the proposed solution | Score from 0 to 100% |
| **5. Environmental Sustainability Indicators (EnSI)** | | |
| 5.1 Index of adherence of the solution to the SDGs | Adherence of the solution to the SDGs | Score from 0 to 100% |

Adpted from Topiol & Berkeley, 2003; Stanitsas & Kirytopoulos (2021)

The KPIs proposed in Table 5 can be applied in a context of collaborative projects, within the international partnership of the SDG Challenge project, and they can measure all pillars of sustainability, whether economic, social and environmental.

Project management aims to assess whether the scope of the projects has been met, whether the proposed solution presents technical feasibility through validation with stakeholders, and whether the proposed solution has practical applicability. Indicators of economic sustainability are related to the return on investment, that is, in addition to presenting a solution, the student must be able to demonstrate that this solution is economically viable, as demonstrated by the Net Present Value (NPV) indices, Internal Rate Return (IRR) and Payback. Social sustainability indicators concern the number of collectors/waste pickers benefiting and how satisfied they are with the proposed solution, as it will impact their workplace within the cooperative, or their personal life. Regarding environmental sustainability indicators, it is necessary to observe the adherence of the solution proposed by students to the SDGs, through a list of questions linked to each SDG and which must be applied to each specific project. This list of questions to assess a project's adherence to the SDGs is a delivery of a product from a project being developed this semester by the international partnership.

It is important to highlight that one of the focuses of the international partnership is to increase the level of student learning. This can be measured by the student's evolution at the beginning of the project and at the end, in relation to technical and transversal skills. The student engagement index can be measured by the level of collaboration between students from different universities, and participating in online meetings during the semester with the exchange of information between projects is one way to evaluate this engagement. Aspects such as cultural differences denote a great experience for students, and dealing with the resolution of real problems related to solid waste and collectors of recyclable materials add to the search for solutions to social problems.

Within the presented proposal, during the 2023 semester it was possible to gather Project Key Management Indicators (PKMI) indicators in three projects within the context of the international partnership. These projects were assessed by two supervising professors, who examined the following: i) Fundraising, which facilitated event planning, content support material, management and indicators; ii) Sustainability Hub, which assessed users journeys of the sustainability hub application; and iii) PUMA Sustainable Impact Module, that allowed a study of the SDGs and their respective impacts on projects. These projects were evaluated in three aspects:

1. Scope compliance index: all planned deliveries and actual deliveries were verified through PM Canvas.
2. Solution applicability index: evaluated by using a Likert scale, ranging from 0 representing not applicable at all to 100 representing highly applicable.
3. Technical feasibility of the proposed solution: also evaluated by using a Likert scale, ranging from 0 representing not applicable at all to 100 representing highly applicable.

This evaluation enabled the creation of a preliminary dashboard, as depicted in Figure 2.

Figure 2 displays a dashboard with Project Key Management Indicators (PKMI) for three projects titled Fundraising, Sustainability Hub, and PUMA Sustainable Impact Module developed in the Production System Project 5 (PSP5) course of the Production Engineering program at the University of Brasília. It is important to notice that the projects have not been developed yet. They will be subject to evaluation in the following semester by other PSPs student´s teams. All projects demonstrated good performance in the scope compliance index, indicating that the planned deliverables were achieved as expected. Regarding the feasibility of the proposed solution and technical viability, the Fundraising project and the PUMA Sustainable Impact Module proved to be applicable and technically feasible, according to stakeholders' perspectives. However, the Sustainability Hub project showed technical feasibility but did not demonstrate applicability in its solution. These results underscore the importance of evaluating not only scope compliance related to project delivery but also technical viability and practical applicability. It is worth emphasizing the importance of measuring other indicators related to sustainability and student learning level to ensure the success of proposed solutions in future projects.

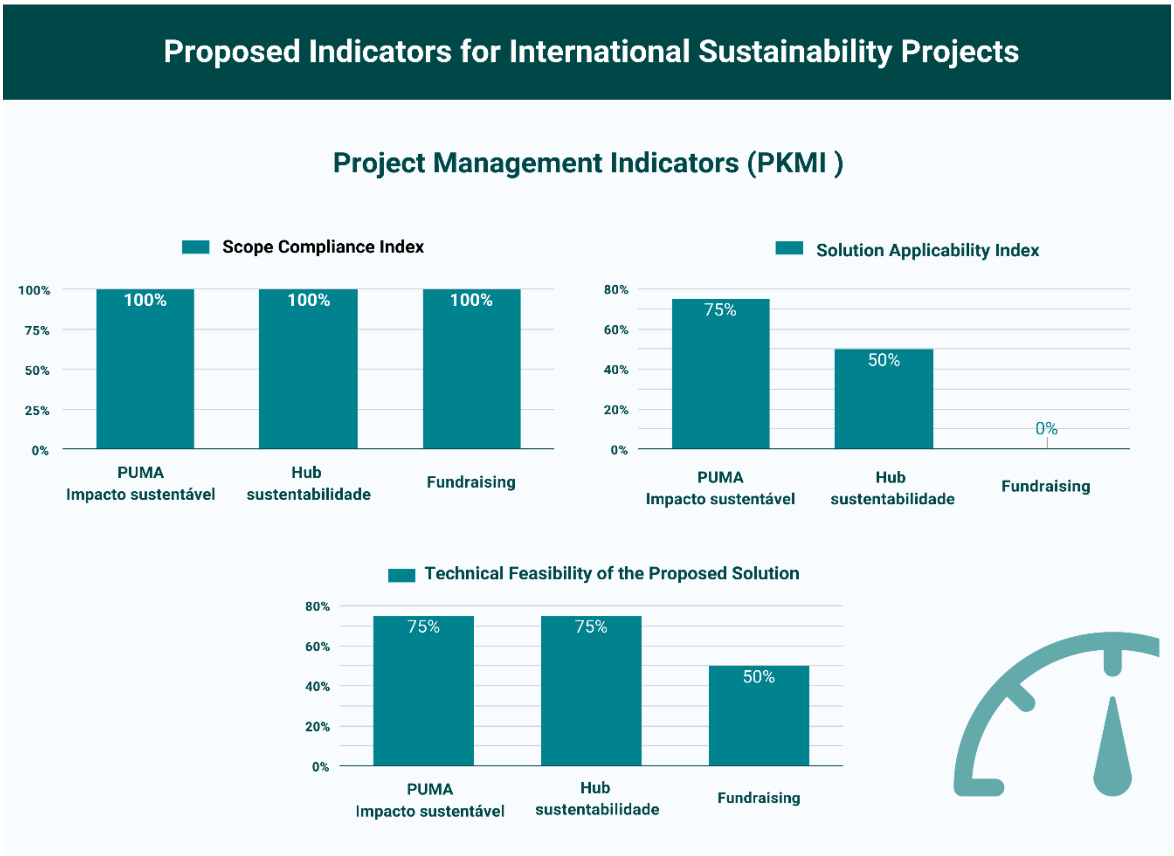


Figure 2. Project Key Management Indicators (PKMI) dashboard.

The results depicted in Figure 2 illustrate the collection of project indicators (item 1 in Table 5) due to the absence of a dedicated tool for gathering indicators related to learning levels and sustainability. To address this, we propose the implementation of a data collection tool for use by students at the project's conclusion. This will facilitate the calculation of all indicators outlined in Table 5. Additionally, this tool is integrated with Looker Studio, which will generate dashboard visualizations, enhancing the evaluation and measurement of the project's impacts on sustainability and learning outcomes.

# 5 Conclusion

Problem-based learning projects on the realm of Education for Sustainable Development also meets the need for key performance indicators, in order to help measure the projects capability to attain certain levels of expectation among stakeholders. This paper has presented how these indicators may be proposed and applied, both for projects evaluation issues as well as how they can impact the real world issues such as the UN 2030 education agenda.

Thus, we have presented some general-purpose project impact indicators that can be suitable for the context of organizations, such as governance, workers, community, environment itself and customers. Other indicators used in PBL approaches are also available to foster this approach of providing specific KPI of the sustainability-related education projects, such as: teamwork balance, leadership, resolute capability, planning creations and updates, version control and deadline fulfillment. The state of the art has showed that by taking these approaches as reference, one may think how projects can be measured under the premises of sustainability.

We proposed in this paper the use of 9 indicators that can be applied to assess the impact of collaborative projects. These projects are the result of a PBL and PjBL approach at the University of Brasília in the context of the SDG Challenge with the participation of other international institutions. The indicators were gathered into 5 categories as follows: 1. Project key management indicators are scope compliance index, technical feasibility of the solution, solution applicability index; 2. Learning indicators are student engagement index and learning level; 3. Economic sustainability indicators which were based on economic viability and return of investment are VPL-NPV, TIR and payback; 4. Social sustainability indicators are index of benefited stakeholders and satisfaction with the solution and finally 5. Environmental sustainability indicators is the index of adherence of the solution to the SDGs.

These indicators were then applied in the course of a 2023 semester, and projects were evaluated under the aspect of scope compliance index, solution applicability index as well as technical feasibility of the solution. The analysis conducted with the use of indicators showed that all projects attained 100% of scope compliance. The solution applicability index was highly achieved by one project, buy not achieved by the others. Technical viability was also high in all three projects analysis. Therefore, we also concluded that it is possible to focus on the impact of projects in sustainability and to withdraw conclusions about their social relevance and financial feasibility with the use of these indicators. We understand the limits of the present analysis and the need to validate the results in a wider range number of projects as well as in other areas where sustainability is important. The next steps of this approach are to conduct a broader analysis considering all the proposed indicators in order to evaluate their application and efficiency.

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# Enhancing Learning with Block Programming in Educational Robots

Ana Caroline R. Braz[1], Marcus Jessé A. Oliveira[1], Carla M. C. C. Koike[1], Dianne M. Viana[1], Jones Yudi M. A. Silva[1]

[1] University of Brasília, Brasília, Brazil

Email: braz.ana@aluno.unb.br, marcus.jesse@aluno.unb.br, ckoike@unb.br, diannemv@unb.br, jonesyudi@unb.br

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**Abstract**

The block programming language allows users to create programs using visual elements that represent different commands and that can be connected to form programming code. Usually, this type of programming language is employed by kids and teenagers because of their accessibility, interactive interface, and easiness to develop and understand programs. Blockly is a set of libraries that provides a variety of programming blocks, representing programming language instructions and it can be used to build block-based visual programming libraries. The Ereko Research Group, at University of Brasília, works with mobile robots applied in STEM and robotics education, and several hands-on workshops are held every year. It was noticed, during the workshops, that programming presented several difficulties for the students. Therefore, the main objective of this work is to develop a library of visual blocks for each robotic educational model at Ereko, to ease the robots programming, code development, as well as code understanding and comprehension from workshop participants. The library development methodology consists in stages of definition, requirements analysis, library design, implementation, testing and documentation. The results obtained during the test of system and software usability show that the software interface presents good appearance and the library elements are well structured, however it was mentioned by the software test participants some difficulties about a certain redundancy of the blocks as well as the non-editable areas. Despite that, it is believed that the proposed system would simplify teaching arduino and programming, as well as facilitate the learning.

**Keywords**: Active Learning; Block Programming; Education Models; Robotics.

## 1 Introduction

It is notorious that programming presents big difficulties for university students (Pereira et al., 2019; Lima et al., 2020; Araujo et al., 2021; Braz et al., 2021), mainly because it demands high cognitive capacity to understand problems and write codes necessary for their resolution (Freitas Júnior et al., 2020; Fonseca et al., 2019; Lima et al., 2020; Luxton-Reilly et al., 2018; Souza, 2018). Over the years, several methods have emerged, such as those proposed by Saleiro et al. (2013) and Iturrate et al. (2013), which target the application of robotics in the development of programming learning environments. In these projects, robotics acts as a context for formulating and verifying hypotheses. Initiatives with this purpose seek to use robotics and technology in the educational field to motivate students and simplify the learning process.

In this sense, visual programming languages (VPL) allow users to create programs using graphic elements, such as blocks or flow diagrams, that represent different commands and can be interconnected to form codes. Currently, this type of approach is widely adopted in teaching children and adolescents due to its intuitive and accessible interface, which facilitates the process of developing, understanding and learning programming (Souza, 2018; Heinen, 2015; Pasternak, 2009; Ribas et al., 2016). The use of visual programming languages (VPL) makes it possible to mitigate several difficulties associated with traditional programming languages, such as problems related to syntax and complex system configurations. In addition to simplifying these technical aspects, VPLs encourage greater interest and engagement in learning computational logic. Furthermore, this approach favours the development of essential skills, including logical reasoning, critical reflection and autonomy, through strategies based on problem solving (da Silva Marinho et al., 2017; Souza, 2018).

Blockly (Google, 2024a) is a set of libraries developed by Google with the purpose of promoting programming education. Additionally, by connecting its blocks, it is possible to translate into multiple programming languages, including JavaScript, Python, PHP, Lua and Dart. Also, Blockly offers a wide selection of blocks that represent programming language instructions, ranging from simple variable declarations to complex mathematical operations, which significantly expands its capabilities to meet diverse software development requirements.

The Ereko research group at the University of Brasilia is dedicated to the study of educational robotics models, covering modular robots, mobile robots with wheels, and other similar devices. During the university extension workshops, held annually by the group, it was noticed that participants experienced considerable difficulty in dealing with programming. Therefore, the main objective of this article is to develop specific block libraries for each educational robotic model created by the group. These libraries aim not only to ease the university students in the robot project, construction and assembly, but also to simplify the process of robot programming by middle school teachers during the workshops, since block language is more suitable for younger school students. The use of block language is particularly advantageous because it allows students to focus on logical and structural aspects of programming. This makes the learning process more engaging and less intimidating, which is crucial for less experienced students (da Silva Marinho et al., 2017; Souza, 2018; Ribas et al., 2016). Additionally, the article aims to present the translation into C language, used when programming Arduino like devices. The library development follows a systematic sequence of stages, from requirements definition and analysis to library design, identification of necessary blocks, implementation, testing and documentation.

The paper is organized as follows. Section 2 discusses the educational models that served as the basis for the development of libraries. In Section 3, the methodology adopted is explained, while in Section 4 the results of the tests carried out will be presented. The conclusion and future perspectives are addressed in Section 5.

# 2 Educational Models of Ereko

This section descriptively presents the robot models used for creating the first test libraries. In section 2.1, an Anthropomorphic Robot is presented, while in section 2.2 a Wheeled Robot is described.

## 2.1 Ereko Anthropomorphic Robot

The Anthropomorphic robot developed by Ereko is a simple device designed specifically to address fundamental principles in robotics education. It is used in the extension hands on workshops with the purpose of introducing basic concepts, such as elementary programming with Arduino, assembling circuits using breadboards, as well as to introduce 3D modelling and printing, a technique used in the production of its parts.

This robot is made up of two main parts: the body and the head. The body acts as a support structure for a servo motor, to which the head is directly attached on its axis. The head, in turn, contains two LEDs, representing the eyes, and a buzzer taking the place of the mouth. Therefore, during the workshops, participants practice controlling the head rotation angle using the servo motor, activating the LEDs to emit flashes and generating buzzer sounds using a button or automatically, depending on the approach.

Although this robot is widely used in Ereko Group workshops for robotics beginners, it is common for participants to face challenges in both assembling the circuits and programming the device.

## 2.2 Ereko Wheeled Robot

The Wheeled Robot developed by Ereko is a mobile robot with differential drive, designed to introduce medium and high complexity concepts to beginners in the field of robotics, as opposed to the Anthropomorphic robot previously described in section 2.1.

The main structure of the robot is made up of a chassis that supports the essential components for its operation, such as Arduino, breadboard, H bridge, batteries, DC motors and wheels. All parts are manufactured using 3D printing, and workshop participants receive instruction in using the necessary tools to reproduce, modify and improve existing robot parts. Furthermore, they can model additional parts according to the specific demands of the project. The robot includes a Bluetooth module that communicates with a smartphone and transmits information to the Arduino via the serial port.

Due to its versatile nature, the wheeled robot allows the integration of other components to explore more advanced concepts. It is feasible to easily integrate ultrasonic sensors in strategic positions on the front and back of the robot, allowing participants to investigate data acquisition and plan, in programming, the robot's response when detecting an obstacle in front of it. A particularly interesting addition is a trailer equipped with a robotic arm and gripper, which can pose a motivating challenge for workshop participants, where they need to not only program the arm, but also control the robot's movement as it tows the trailer.

## 2.3 Workshops

The robots described above are used in workshops aimed at the students and teachers of secondary education in public schools. These training workshops are held only for teachers, and they cover both robots as well as pedagogical methodologies necessary for their use. This training workshop prepares teachers to replicate the sessions with their students and the covered contents can be easily adjusted, allowing a more effective adaptation to the specific needs of the school where they work.

The workshops are divided in two modules of four workshops each: the first one is based in the first robot model (the Anthropomorphic Robot) and covers the fundamental concepts of 3D modelling and printing, programming logic, assembly of basic circuits on protoboard and Arduino. The second one is based in the second robot model (the Wheeled Robot) and it focuses on more advanced concepts such as the use of sensors, DC motors, H-bridge and Bluetooth communication, in addition to creating applications on the AppInventor platform (MIT, 2024).

# 3 Methodology

This section presents the sequence of steps used in creating the block system for programming the robots. The first section presents the block library was created and the second section describes the interface where these blocks are used in programming.

## 3.1 Block Library

Blockly, developed by Google (2024a), consists of a set of libraries for visual programming. In order to encourage programming learning, this library is accompanied by a customization editor, designed to introduce programming concepts by connecting blocks, generating clean code in the chosen programming language, as well as enabling the editing and customization of this code. Widely adopted by children and teenagers, this library encourages them to create their own animations and interactive games.

Blockly offers a variety of blocks that represent instructions found in various programming languages, ranging from variable declarations to mathematical, logical and relational operations, as well as conditional and repetition structures, among other features. By interconnecting these blocks, the environment is capable of automatically converting to languages such as JavaScript, Python, PHP, Lua and Dart. Therefore, Blockly has the following advantages:

- Open Source: Available with an open-source license in its own repository on GitHub;
- Extensible: Capable of satisfying all user demands;
- Code export: Offers the ability to convert blocks into conventional programming languages;
- Versatile: In addition to being an educational tool, it also supports multiple languages, along with a wide variety of functionalities; and
- Multilingual: Available in translation into more than 40 languages.

To create the libraries, the Blockly Factory tool (Google, 2024b) (Figure 1) was used, a development platform that enables users to design and customize blocks of code according to their individual needs. It works as an authoring tool, simplifying the generation of custom programming languages or the expansion of existing ones. Within this context, users have the possibility of specifying the available blocks, their functionalities and interconnection methods to form programs, such as selecting colours, formats, behaviours, returns, options, text fields, among other aspects. This simplified approach to programming replaces manually writing code with a drag-and-drop interface, making the coding process more accessible and intuitive, especially for those just starting out.

For these reasons, it was considered feasible to create specific libraries for each educational model used by the Ereko research group, not relying exclusively on Blockly brings advantages, such as the ability to customize blocks, more optimized performance, full control over the code to be created, flexibility to deal with specific group situations, efficient maintenance and integration with other tools. This makes it possible to adjust the code according to students' needs, ensuring effectiveness and continuous progress.

## 3.2 Interface Creation

Using JavaScript, HTML and CSS programming languages, a test interface was developed (Figure 1) with the purpose of allowing the visualization of the implemented libraries, as well as demonstrating the conversion of blocks to the C programming language. Furthermore, the user is offered the option of downloading the resulting code with the "`.ino`" extension, compatible with Arduino integrated development environments (IDEs), simplifying the process of compiling and executing the program, even for those who do not have prior knowledge of C programming language.

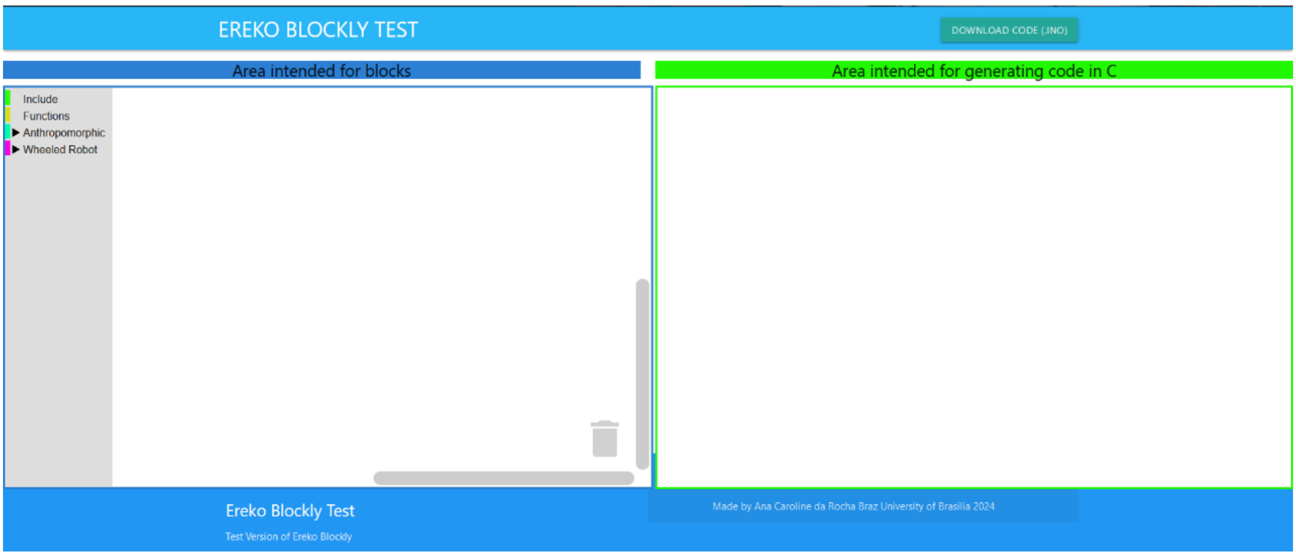


Figure 1. Test Version Interface

# 4 Results

Currently, two libraries have been developed, one for each educational robot described in section 2. Tests were carried out with the students and teachers, as well as members of the Ereko group. The tests were related both to the system functioning and to the software usability, with the purpose of collecting suggestions for improvement and feedback.

## 4.1 General Library

For general purposes, a category called "Include" (Figure 2) has been established for libraries to be added during programming. Additionally, there is the "Functions" category, which contains the main code functions to be transferred to the Arduino, such as the "void setup" and "void loop" functions (Figure 3).

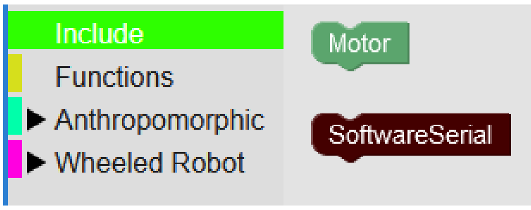


Figure 2. Include Library

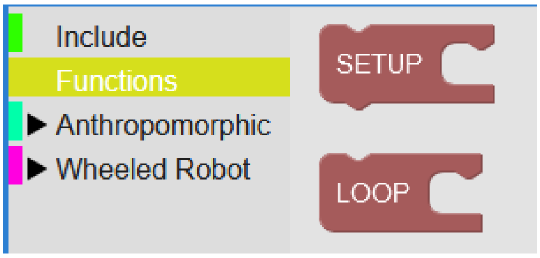


Figure 3. Function Library

## 4.2 Results of Ereko Anthropomorphic Robot

For the Anthropomorphic Robot, a specific library was developed, divided into sections related to its assembly during the workshops held, aiming to make it easier for participating teachers and students. These sections include:

- Eyes (Figure 4): blocks related to the LEDs in the robot's eyes;
- Mouth: Includes the blocks related to the buzzer;
- Head: Contains the blocks related to the motor that moves the head; and
- General: Incorporates function blocks that can be used in both the "void setup" and the "void loop".

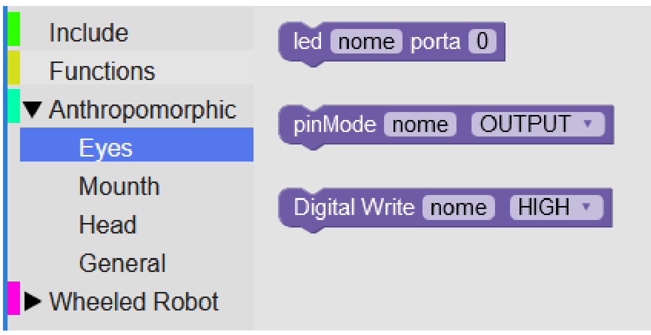


Figure 4. Ereko Anthropomorphic Robot – Eyes Library example

Through the developed interface and library, tests were conducted and improvements were implemented over time (Figure 5). During the assembly process, C code is automatically generated alongside for the user. When finished, the user can use the download button to generate the file with the ".ino" extension, compatible with the Arduino IDE. This way, the code can be compiled and executed easily.

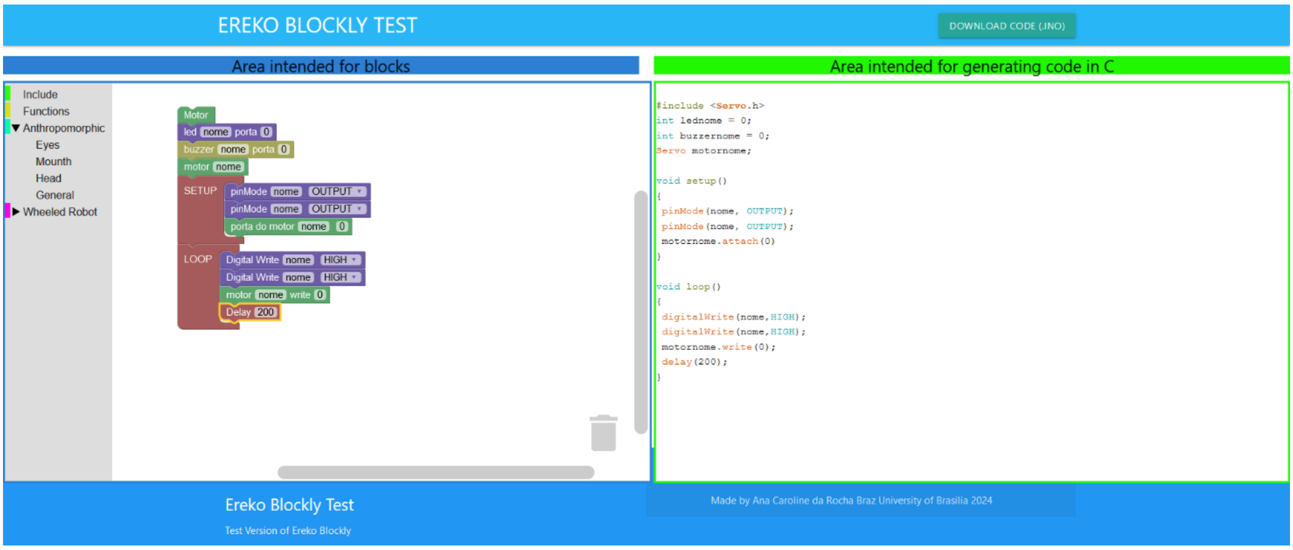


Figure 5. Test example for Ereko Anthropomorphic Robot

### 4.3 Results of Ereko Wheeled Robot

For the Anthropomorphic Robot, a comprehensive library was developed, providing greater flexibility in editing blocks for the user. Thus, the following categories are presented:

- Serial (Figure 6): This category is related to asynchronous communication between an Arduino board and a computer or other device;
- Functions: This category encompasses blocks associated with pin configuration, digital values, component intensity control, conversion of value ranges and conditional structures; and
- Variables: This category includes blocks for declaring variables, such as bytes or integers (int). Furthermore, it has an assignment block, allowing variables already declared to be later used to receive results from operations.

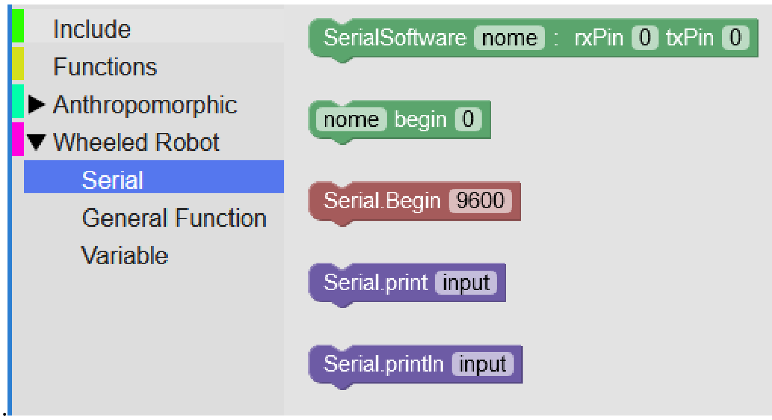


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Figure 6. Ereko Wheeled Robot – Serial Library example

In the same way as for the anthropomorphic robot, tests were conducted and improvements were implemented over time, using the interface and library developed. During the assembly process, C code is automatically generated alongside for the user. When finished, the user can use the download button to generate the file with the ".ino" extension, compatible with the Arduino IDE, thus facilitating the compilation and execution of the code.

## 4.4 System functioning and software usability

In order to check the integrity of the software, tests of system and software usability were done. In order to help the test participants, initial explanations about the software were made, such as what is the system objective and how is it works. After that, the participant should do the test using a code example from both robot models presented in section 2. Following, they should answer a form, providing feedback and improvement suggestions.

In the form, questions about experience of the users were made, for example, if it was the first contact with Arduino and block programming. In addition, questions related to the interface and the library functionalities, general blocks and layout are also present in the form. Furthermore, questions about how much efficiency the software could be in the teaching of arduino and programming concepts.

In total, 9 feedback answers were collected, of which only 2 people used Arduino for the first time and 1 used block programming for the first time. In general, the layout was considered very pleasant and received improvement suggestions like the ability to change the colours, the possibility to increase or decrease each area and the possibility to edit the code C area. In relation to the block elements, they also had a very good reception, however there was some balanced between the good and bad ratings about how intuitive the blocks are. Also, suggestions for improving blocks functionality descriptions, abstraction of details and code structure in C were proposed.

The first library, related to the Anthropomorphic robot, had very good ratings and 8 people think it is possible to learn programming in the proposed way. However, with respect to the structure within the library there was a balance of opinions. In addition, the need of reducing block redundancy, the creation of blocks with more advanced functions and the separation of functions before code were suggested. For the second library, using the Wheeled robot, the users also rated it as having pleasant appearance and 8 people think it is possible to learn programming in the proposed way. Moreover, again, the structure within the library showed some balance of opinions, and suggestions were made regarding the need of improving the general robot movimentation blocks, of improving the form of blocks connection and their respective codes, as well as adding more blocks.

Regarding the use of the system to teach programming, 66,7% says that they would use it and 77,8% believe that the software facilitates teaching arduino. In addition, 88,9% believe that the application is effective in teaching programming concepts. These data suggest that the software can not only make learning more accessible and engaging but, also it can be effective in conveying complex concepts in an intuitive and practical way. Some users have reported difficulties with locating certain blocks, the non-editing feature in the code area and the fact that some blocks already contain variable names. Despite this, one of the final comments highlighted that, compared to the Tinkercad platform (Tinkercad, 2024), used for design and 3D modelling, the proposed system is much more intuitive for users.

# 5 Conclusion and Future Perspectives

In the present study, the use of block programming for educational models was described with the objective of creating exclusive libraries for the robotic models developed by the Ereko research group at the University of Brasilia. This process was conducted systematically, aiming to guarantee efficiency, flexibility and integration of the developed blocks. Using the Blockly tool to create the new system, the results obtained in the test of system and software usability demonstrate that the blocks developed for the Anthropomorphic Robot and Wheeled Robot models were very good pleasant about appearance but had a balance opinion about the separation of blocks in the library. Additionally, also had difficulties with locating certain blocks of some blocks, a non-edit code area, some blocks already contain variable names and redundancy blocks. Besides that, most participants would use the application and believe that it would facilitate the teaching of arduino, in addition to believing that it is effective in teaching programming concepts.

For future work, it is planned to incorporate the improvement suggestions provided by the group, which include reducing the redundancy of blocks, improving their code, enabling editing in the C code area, improving the colour palette of the libraries and evaluate and improve the system structure, as well as adding explanations about the functionalities of the blocks. Furthermore, we intend to expand the work to other educational models developed by the group.

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# Innovation Skills in Engineering Education as a Catalyst for Sustainability: a preliminary Literature Review

Marien Rocio Barrera Gómez[1], Liliana Fernández Samacá [1]

[1] Grupo Investigación en Procesamiento de Señales – DSP, Universidad Pedagógica y Tecnológica de Colombia, Sogamoso, Colombia

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

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**Abstract**

The research unfolds a preliminary literature review to establish the state of the art regarding sustainability and its relationship with developing innovative skills in engineering. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was the method employed through a structured approach for designing, conducting, and reporting with systematic stages, taking like the primary goal the bias reduction and increasing the reproducibility of the results to ensure the transparency in the process, enhancing the credibility and reliability of the findings. The review assessed the current knowledge production of innovative skills in engineering students and how they impact sustainable development. It aims to thoroughly examine related works by analyzing their contributions and identifying areas that warrant further investigation. The resulting narrative allowed for a comprehensive overview of the relation, identifying gaps in existing knowledge and potential avenues for methodological enhancement. The results show that most of the contributions are devoted to interventions in which curricular approaches intend to create new learning scenarios for students, and therefore, students are the center of action. Still, few works stress the teaching practice or the other resources management, showing a set of interesting gaps, especially considering that exemplarity and inspiration are variables explored to foster the higher education process in engineering in different approaches.

**Keywords**: Innovation; Engineering Education; sustainability; Higher education.

## 1 Introduction

Sustainability is a multidimensional concept that promotes ensuring the well-being of current and future generations through the responsible management of resources, equitable development, and long-term resilience. For this reason, sustainability is based on four pillars: environmental, social, political, and economic. Therefore, the environment can be seen as a system, where a community lives and interacts in harmony and respect, going beyond the ecological aspect; the social aspect is part of the environmental resources focusing on the well-being of individuals and communities, the political aspect is related to the policy framework to manage the resources, and the economic aspects relate to fostering economic growth considering equity and respect (UNESCO, 2023).

This vision is established in the Global Sustainable Management Strategy 2020-2030, which started in 2019 with the strategy´s baseline for operation, then transformed into policy in 2020, which was structured through the road map to be adopted in 2021 and declared as Phase II. Later, in 2022, staff training began addressing the Building Research Establishment Environmental Assessment Method (BREEAM) certification, and in 2023, UNESCO introduced the Environmental and Social Safeguards Framework (ESSF) (UNESCO, 2023). Currently, this vision continues to evolve according to global conditions, highlighting the role of education in raising citizens' awareness to promote critical thinking guided by the principles of equity, collaboration, and inclusion (UNESCO, 2017).

Many countries have adopted The Global Sustainable Management strategy, including Colombia, and institutions like the Organization for Economic Cooperation and Development (OCDE) support member and partner countries in integrating sustainability into their policies and practices through policy advice, policy coherence, capacity building, monitoring, review of strategies, and adoption alternatives and learning. This support is addressed in four action areas: i) ways and tools to apply the sustainable development Goals (SDG), ii) data analysis for monitoring the implementation, iii) support for integrating planning and experiences, and finally, iv) reflection and improvement (OCDE, 2017).

In this context, the OCDE has developed a structure addressed by the Oslo Manual, which has been adapted according to the conditions of different territories like Bogota Manual oriented mainly to developing countries or Frascati Manual for developed countries (OECD & Eurostat, 2018). This structure is supported by external tools like the Global Innovation Index (GII), which is monitored by the World Intellectual Property Organization (WIPO). This measure observes the innovation dynamic from incomes, resources, capacities, results and impacts; which are, in turn, transversal to the four sustainable pillars: environmental, social, political and economic. Thus, one of the most important topics related to educational issues, at all levels, are: knowledge absorption, knowledge production and knowledge transfer (GII, 2019).

Colombia has prioritized science development through diverse strategies; one of those is the Council of the Wise, a group of experts in different areas charged by the government of Colombia to produce recommendations about the country's future, including sustainable development. The recommendations of the International Council of the Wise, known in Spanish as *Misión de Sabios*, outline specific goals for balanced development, including quality education and productive growth. The National Policy for Science, Technology, and Innovation, outlined in CONPES 4069 (In Colombia, the Consejo Nacional de Política Económica y Social CONPES is a set of policies oriented to attend specific problems relate to social and economic aspects), sets a 10-year roadmap emphasizing sustainable development. However, challenges persist, such as insufficient STEAM vocations and weak knowledge transfer environments. The Missions oriented Policies – those that emerge for government strategies called Missions, for example, *Misión de Sabio*s – aims to address these gaps, explicitly focusing on science for peace and citizenship. Moreover, Knowledge absorption and production in Colombia are close to the global statistical average. However, Knowledge transfer is significantly lower; this indicates that the absorption of knowledge to improve sustainability by society and industry is still low (COMPITE, 2021).

At the regional level, for example, in places located in the Andean mountains, such as Boyacá province, which are characterized by its biodiversity, the priorities for sustainable development include discussions about bio-economy that involve topics like the impact on agriculture, water management, and formulation of a new sustainable model. Despite advancements, challenges remain, including brain drain and the need for academia-industry collaboration. Considering that globally, initiatives emphasize experiential learning and innovative teaching methods to bridge knowledge gaps, in the same way, this work aims to strengthen Boyacá's scientific ecosystem by designing educational approaches that use real-world challenges and critical social needs as learning triggers for promoting the innovation skills, and consequently to improve the region's competitiveness by knowledge transfer.

Knowledge transfer implies developing appropriate solutions, and the engineering professions play a relevant role in the process (Newman, 2024). The term 'appropriate' involves many dimensions, including the sustainability view. These solutions will be more significant if engineering faculties are closer to the industrial and social sectors, taking advantage of their interdependent relation (professions/ employment), which appears usual, but what happens with the effectiveness of this link? Then, an extra question emerges ¿how can we enhance creative and innovative skills in engineering education, exploiting the relationship with society and industry to design appropriate solutions from a sustainability view?

In a Colombian employer survey on human capital, respondents indicated increased difficulty recruiting workers, rising from 36% in 2009 to 61% in 2022. This figure is lower than the global statistic average. According to the Chief executive Officer´s (CEO), the gap is associated with quality, quantity, and skill pertinence challenges, emphasizing the ability to transform theory into appropriable results; this context contrasts with the number of bachelor´s graduates, which increased by 16,7% between 2015 and 2021 (Consejo Privado de Competitividad, 2023).

A similar situation occurs in different territories. According to UNESCO, some global education challenges to promote sustainable development are environmental awareness, curriculum integration, teacher training, interdisciplinary approaches, global citizenship, partnership and collaboration, access to education, innovation and technology, lifelong learning, monitoring, and evaluation (UNESCO, 2020). Likewise, it is also important to consider alternatives for facing these challenges through new educational interventions that involve, for example, the design of Active Learning (AL) strategies or student-centered approaches. The AL involves interpreting phenomena through various lenses to understand the world, where learners assimilate the knowledge simultaneously whereas they live an experience (Bringuier et al., 1980); in turn, this process needs to have a meaningful impact on the learner and their community or institution, demonstrating its utility value. Thus, the abilities of reflection, abstraction, and concretion play a relevant role in successful learning through experiences (Kolb, 2014).

The student-centered approaches are usually designed to promote critical thinking and collaborative work among diverse knowledge areas. It provides strategies to encourage students to explore new ideas and perspectives, resulting in improved performance among engineering students, particularly in STEAM and, consequently, in an alternative for promoting creativity and innovation skills (Freeman et al., 2014).

## 2 Method

This work is an exploratory literature review to assess the current knowledge of innovative skills among engineering students and how they impact sustainable development. It aims to thoroughly examine related works by analyzing their contributions and identifying areas that warrant further investigation (Petticrew & Roberts, 2006). The research question guiding the overall study evaluates each study's contribution. The resulting narrative serves as a comprehensive overview of the topic, identifying gaps in existing knowledge and potential avenues for methodological enhancement (Boland et al., 2017).

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was the method employed. PRISMA offers a structured approach for designing, conducting, and reporting systematic reviews, with the primary goal of reducing bias and increasing the reproducibility of the results (Moher et al., 2009). Following PRISMA guidelines ensures that the review process is transparent and methodologically sound, enhancing the credibility and reliability of the findings.

To identify relevant information, the search focused on three main clusters: active learning, higher education and sustainability. The search was conducted in the Scopus data base using the following equation:

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(TITLE-ABS-KEY (("transform* learn*" OR "activ* lean*" OR "student focused lean*" )) AND TITLE-ABS-KEY (( "higher education" OR "higher education institution*" OR "hei*" OR "universit*" )) AND TITLE-ABS-KEY "sustainable development" OR "SDG" OR "2030 agenda")).
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Initially, 111 documents were retrieved. These were filtered using exclusion criteria such as publication date, document type, type of results, and relation with the topic. The final dataset consisted of 70 documents, as shown in Figure 1. We include the date rank from 2015 to 2024, coinciding with the implementation of the 2023 agenda. In the reviewing process, we also consider the type of documents and the quality of the publication. Therefore, we only selected articles and book chapters.

Regarding the content of the papers, we applied two filters; the first filter was related to the stage of the research process, choosing only final publications that provide more details, in-depth analysis, and thorough discussions. The second filter was the topic coherence with the research question. This last was the only one applied with a manual review through a careful evaluation, ensuring a precise selection of relevant papers.

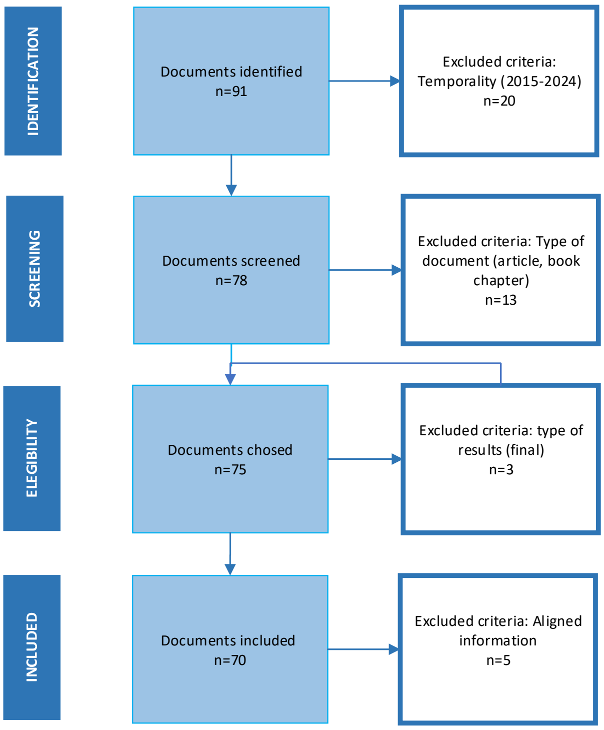
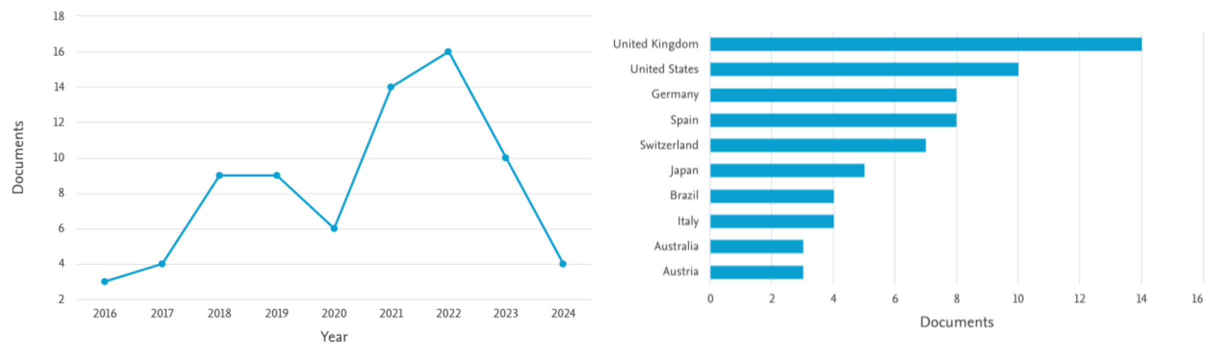



Figure 1. PRISMA chart (Source: the authors, 2024).

We used a bibliometric tool, such as a visual strategy, to analyze documents and identify relationship variables and information trends. This analysis allowed for linking insights contexts with the expected research outputs.

# 3 Results and discussion

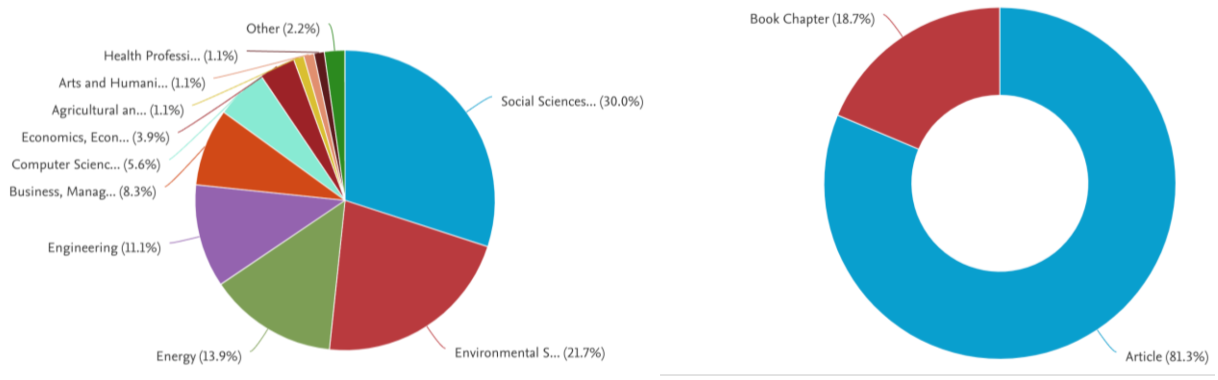
Taking into account the limit established with the keyword used in the research question presented in the method: (TITLE-ABS-KEY (("transform* learn*" OR "activ* lean*" OR "student focused lean*" )) AND TITLE-ABS-KEY (( "higher education" OR "higher education institution*" OR "hei*" OR "universit*" )) AND TITLE-ABS-KEY "sustainable development" OR "SDG" OR "2030 agenda). The trends appreciated in knowledge production increased during the pandemic and post-pandemic period, as depicted in Figure 2. This rise was due to the global situation bumping out the socio-economic challenges. However, by 2022, the trend declined as life returned to normal. Most countries interested in the topic are European, with only Brazil and Australia from outside Europe in the top ten. The results show that the European Union is more committed to the explored topics.




Note: Left figure, production by year.   Right figure, the production by country.

Figure 2. Knowledge production (Source: Scopus 2024)

The knowledge is associated in more than 50% by two sub-areas, social and environmental sciences, followed by energy and engineering with 25%. In contrast, health, art, and agriculture are the sub-areas with lower production, as depicted in Figure 3. This landscape shows an opportunity for deeper exploration in the engineering sub-area. Another essential characteristic is that 80% of publications that are part of the knowledge body are articles; this means that the studied sample represents contributions that have faced a strict evaluation process.




Note: Left figure, sub-area classification.  Right figure, document type.

Figure 3. Documents classification (Source: Scopus 2024)

About the content of the 70 documents, the trend has evolved from emphasizing critical thinking and transformative learning to complementing sustainable development, as depicted in Figure 4.  These concepts are encompassed in a process that begins with an information analysis from diverse perspectives.  Likewise, the results show that students are encouraged to reflect and propose solutions,  contributing to sustainable development, but there are few details about how to do that.

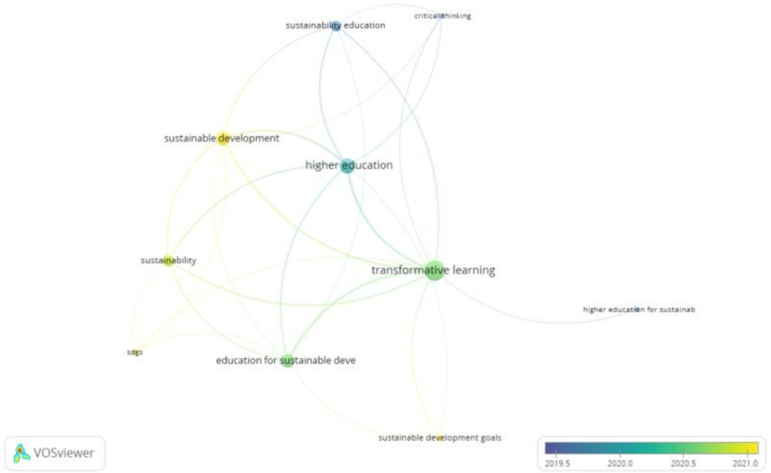



Figure 4. research trend (Source: The authors 2024, though VOSviewer)

The research results have focused on the node sustainable development, with two clusters of information: transformative learning and teaching, as shown in Figure 5. In transformative learning, the most recently explored topics are related to engineering education, specifically curriculum, and students. Regarding the teaching cluster, the more recent issues developed are innovation, teaching training, and educational development.

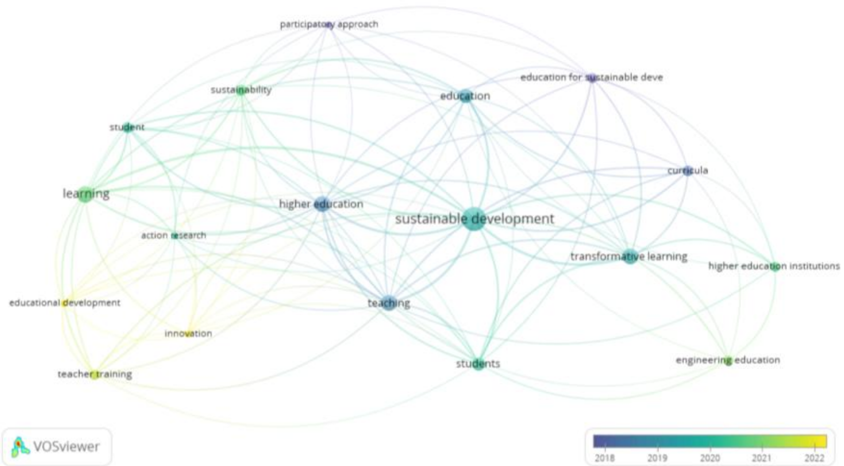



Figure 5. co-occurrence key word analysis (Source: The authors 2024, through VOSviewer)

Two clusters relate to well-founded frameworks about transformative learning. Mezirow defines transformative learning as a continuous process involving understanding, structuring, reflection, depth, and purpose; this proposal is based on thought, feeling, and acting. This process has two layers: the first is the curriculum, which encompasses a set of courses, learning experiences, and educational activities designed for a degree; the second is learning support, which is associated with the experience that serves as a critical thinking trigger to transform individual and social perspectives, values, vision, and discourse (Mezirow, 2000); as well as sustainable development.

One route to connect layers is teaching, like the approach that encourages students to take an active role in their learning, working in teams to solve complex, open-ended problems (Jatmiko et al., 2018). Thus, current trends open the door to exploring educational development approaches toward sustainability through topics like teaching training and educative innovation.

Despite of the large number of publications, the SDG's indicator of the advance in achieving goals shows the Sustainable Development Goal (SDG) 4 “Quality Education” in a worrisome scenario, as depicted in Figure 6. The go-ahead tendency is correct, but the advance is too slow to achieve the goal: "to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all " (CEPAL, 2024).

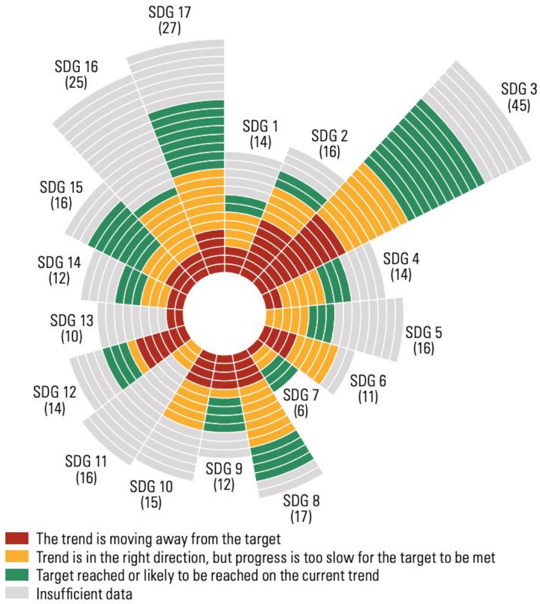



Figure 6. SDG´s trend indicators (Source: CEPAL 2024, The Challenge of Accelerating the 2030 Agenda in Latin America and the Caribbean: Transitions towards Sustainability)

The review analysis results show that researchers focus on transformative learning to support sustainable development. However, to solve the question “How? And when?” it is necessary to explore educational frameworks and their elements like content, approaches, management, and evaluation, as well as their actors or participants, teachers, students, and stakeholders.

## 4 Concluding remarks

This work provides a framework to address deep research, using a strong background of approaches to enhance innovation skills for sustainability inspired by student-based centered models. Thus, observing the objective of many documents, transformative learning studies have been focused on curricula and students; however, the latest trends are oriented to a born trend on teaching training and education, offering a wide view of perspectives for future research.

This work presents an initial literature review analysis about enhancing innovation skills in engineering education, taking transformative teaching as an option. This work provides a preliminary framework for researching the topic and understanding how student-centered learning approaches foster innovative skills and how transformative teaching is a challenge for truly transformative learning. Although observing the consulted works' purposes, transformative learning studies have focused on curricula and students, but, the latest trends show teaching training and innovation for education as alternatives for offering a comprehensive view of perspectives for future research.

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# A Strategy to Transform the Pedagogical Practice of Teaching Teamwork

María P. León[1 2], Carola Hernández[2]

[1] Pontificia Universidad Javeriana, Colombia
[2] Universidad de Los Andes, Colombia

Email: ma-leon@uniandes.edu.co, c-hernan@uniandes.edu.co

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**Abstract**

Organizations worldwide have begun restructuring work around collaborative systems and teamwork to improve problem-solving, innovation, and adaptability. To enhance knowledge appropriation and the development of teamwork competencies, universities have had to incorporate student-centered learning approaches into their curricula. Thus, reforming the Faculty of Engineering of the Pontificia Universidad Javeriana (PUJ) curriculum introduced project-oriented courses. In particular, the Engineering Project Year 1 course brings together second-semester students from different engineering programs who work in groups on the project. Due to the number of students, the course is organized into ten sections, each led by a professor and a coordinator. The course addresses engineering design based on Design Thinking methodology and subsequently proposes the development of a prototype using Lean Start Up methodologies. This study aims to present a strategy that transforms teachers' understanding of what teaching teamwork entails and what strategies can be implemented to teach it. It is qualitative research using the Critical Research methodology proposed by Skovsmose and Borba (2004). This methodology helps researchers and professors collaborate to investigate the educational practice change process through three analytical situations. The analysis of the initial situation shows that the structure of the course can be perceived as facilitating the development of teamwork skills; there are difficulties in its implementation associated with the dynamics between students and between teacher and student. Additionally, it is found that the dominant pedagogical practice is that of a teacher-centered teaching approach, which does not facilitate the generation of a trusting learning environment, a fundamental element in collaboration. The imagined situation involves a better understanding of the role of teachers in teaching teamwork and sharing good practices to achieve it. Finally, the arranged situation presents the challenges of accompanying teachers transforming their pedagogical practice to generate negotiations through reflective conversations to motivate the change.

**Keywords**: Teaching teamwork; Teacher professional development; Critical Research; Teacher roles in PBL

## 1 Introduction

In recent years, organizations worldwide have faced increasingly complex, rapidly evolving, and unpredictable environments. As a result, they have started restructuring their work systems to encourage collaboration and teamwork, aiming to enhance problem-solving, innovation, and adaptability (Kolowsky et Chaw, 2018s). This shift in work dynamics has inevitably affected the skills employers expect from university graduates, emphasizing the need for a broader focus on a teacher-learning process that encompasses not only specific competencies but also general or transversal competencies.

Teamwork competencies have become essential to engineering programs due to the emphasis on collaborative work in organizations (Borrego et al., 2013). This is also because international accreditations like ABET make it mandatory for graduates to have these competencies. Along with problem-solving, critical and reflective thinking, and collaboration skills, universities are now focusing on making students more participative in the search for real solutions through student-centered pedagogical models and active learning (Du *et al.*, 2020). However, this has its own challenges, as teachers must adopt new methodologies that involve different roles for both students and teachers in the teaching-learning process.

The problem-based learning model proposed by Kolmos (2004) explains how not only students and teachers are involved in the teaching-learning process. This model establishes that there must be a concordance between changes in each element of the teaching-learning process. Changes in one element lead to other model elements being restructured to achieve an adequate teaching alignment. Therefore, changes in the competencies to be developed imply that other elements, such as the type of work, resources and physical frameworks, and interactions among students, among others, should be evaluated and aligned to ensure educational quality and teaching alignment (Biggs, 2001).

To foster teamwork competency among engineering students, it is crucial to understand how the elements of the teaching-learning ecosystem and the concept of teamwork are interconnected. According to Roberts et al. (2022), a team is a group of two or more individuals who perform specific functions and interact in an adaptive, interdependent, and dynamic manner toward a shared and valued objective. This definition underscores that teamwork and collaboration are not static but active processes that evolve throughout their life cycle (Bedwell et al., 2012). Facilitating this competence development implies that the curriculum's pedagogical strategies must be aligned. Collaborative Learning (CL) is an educational strategy where learners work together to solve problems, accomplish tasks, or create products. Universities worldwide are increasingly adopting this pedagogical strategy because it helps students develop a range of competencies and because national and international frameworks drive universities to reflect on teaching practices in light of the competencies needed in the workforce.

In line with this, the Faculty of Engineering at the Pontificia Universidad Javeriana (PUJ) has adopted the CDIO (Conceive-Design-Implement-Operate) initiative, which exposes students to real-world problems early in their programs. PUJ's engineering programs have established project-based courses over four years, starting from year one, to help students approach real-life problems. As part of this initiative, all engineering programs at PUJ have introduced project-based courses from year 1 to year 4 to provide students with real-life problem-solving experience. However, despite the availability of a framework for using collaborative learning as a pedagogical strategy consistent with the CDIO model, the curriculum reforms did not include a systematic and continuous teacher training program. Additionally, these courses are challenging for teachers to address since they involve the generation of tools and class dynamics that enable solving real problems, thinking critically, and working collaboratively, which implies a shift related to the teacher's role regarding the interaction with the student and the solution proposed and greater autonomy on the part of the students in terms of exploring the solution. Consequently, ensuring teachers have the tools to shift from traditional to student-centered teaching is impossible.

Regarding the curriculum, the Engineering Project Year 1 course is offered for second-semester Engineering Faculty students. This course introduces students to engineering design processes, emphasizing problem design and problem-solving using Design Thinking tools. Lean start-up methodologies are also taught to help the students develop a prototype. The course problem is related to the Sustainable Development Goals (SDGs), which aim to raise awareness among students about their context and to identify local and national problems. One of the learning outcomes of this course is to enable students to foster a collaborative work environment.

For this reason, tools from the Scrum methodology have been implemented, such as a project management framework that encourages teams to learn from experiences, self-organize, and reflect on results. The methodology must be applied throughout the development of the course's deliverables. Regarding the logistics, this is an extensive course with around 300 students. The course is divided into smaller units of about 25 students each. Each teacher is responsible for supporting five work groups within each course. About ten teachers are required for this course, eight working part-time. The course coordinator is responsible for aligning the course activities and defining the project topics. The coordinator also organizes general meetings with experts on the project topics, coordinates the work of the professors, oversees the final student presentations, addresses any concerns raised by the teachers, and ensures that the teachers are aligned with the proposed learning outcomes.

We have faced some implementation difficulties after running a course for six semesters. One of the challenges is that most professors teaching the course are part-time. Therefore, we have formed two research questions to address the situation: RQ1. Considering the context conditions mentioned above, what are the primary obstacles to creating a collaborative environment for the Year 1 project of the PUJ engineering programs? RQ2. How can the teaching practices of the PUJ professors be transformed to promote the development of teamwork competencies in this course?

## 2 Methodology

This qualitative study is framed in Critical Research (Skovsmose & Borba, 2004). Critical research proposes developing participatory and collaborative research between teachers and researchers to generate transformations in classroom problems, evidencing the interaction between theoretical perspectives and methodologies present when conducting educational research. Skovsmove and Borba state that to generate changes, it is necessary to break with the model of investigating what is and what has happened to investigate what would be possible. Consequently, they suggest that transformation occurs by traversing a triangle between three analytical situations and the relationships between them. In the initial situation, possibilities for transformation are identified by systematically analyzing what happens in the classroom and the learning environment. Based on this analysis, an imagined situation is proposed, which represents the vision of the possibilities and alternatives for change to address what was identified in the initial situation. However, when implementing the proposals for change in the imagined situation, limitations associated with resources and implementation barriers emerge because conditions must permanently restrict the possibilities of realizing everything we imagine. From this disparity emerges the fixed situation as a realistic vision of the imagined situation. Central to critical research are the relationships between situations. These situations represent the negotiation between actors to achieve a specific outcome. They are the conscience of participatory actions and the only way to mobilize someone.

The research team is formed by a doctoral student who is a civil engineer, a lecturer in the course Engineering Project Year 1, and her thesis director, a physicist with a PhD in innovative curricula in science and technology in higher education. They collaborated with three professors (P1, P2, P3) who agreed to participate in the project. They are part-time lecturers with about ten years of experience as part-time lecturers at PUJ and with the course coordinator [P4].

Initial interviews were conducted to understand the professors' perspectives before interventions, and the classes of the same professors were observed during the semester. After interventions, interviews were carried out. The information was processed and categorized according to the theories of constructive alignment (Biggs, 2001) and the collaborative learning theory proposed by Johnson and Johnson (2013).

The information was transcribed and analyzed in the following way: To approach the initial situation, we aimed to understand the conceptions of the Year 1 project course teachers about teamwork and the pedagogical strategy they use in the course. We used pedagogical imagination to propose the imagined situation based on recognizing successful practices and theoretical elements such as transformative learning and constructive alignment. Finally, a practical organization is required to implement what is proposed, giving rise to the arranged situation. When implementing the imagined situation, a practical organization must be carried out, which consists of validating what is possible versus what is imagined.

## 3 Results

### 3.1 Initial situation

The teaching approaches vary across classes. P1 and P2 classes typically involve a lecture for half of the session, followed by project implementation based on initial class observations. In contrast, P3 classes feature more active dynamics, with theory quickly followed by practical application. The master class presents Engineering design concepts and examples from the teacher's professional experience, resulting in limited student participation, mainly through sporadic responses to rhetorical questions. In practical sessions, the teacher rotates among groups, addressing doubts, approving work, and providing specific instructions for improvement. This pattern repeats across all three classes, with teachers actively shaping students' work during group interactions.

In team dynamics [P1, P2, P3], the teacher assumes a central role in guiding students' development of teamwork competencies and managing their learning processes. The teacher mediates group conflicts, often engaging in negotiations and compromises with students to resolve issues. Students typically present problems and await the teacher's intervention to resolve them. While each teacher exhibits varying degrees of control over team dynamics, discussions regarding team performance and management primarily flow from teacher to student. These discussions typically arise at three junctures: when groups bring team conflicts to the teacher's attention, when the teacher identifies subpar product quality, or when student attendance issues arise and become evident to the teacher. However, it is uncommon for teachers to actively foster reflective spaces for students to contemplate teamwork dynamics despite the prevalence of conflicts within teams.

The coordination has established evaluation tools to assess team performance, which are utilized by teachers based on their individual understanding and implementation. For instance, in P2 classes, team-building activities are notably absent, whereas P1 classes adhere closely to coordination directives. In P3 classes, peer evaluations are conducted in real-time, whereas in P2, the evaluation and co-evaluation survey activity is relegated to outside class time due to concerns over content coverage.

The course coordinator emphasizes that each professor has autonomy in course management but encourages dialogue at the semester's end to review course experiences [IP4]. During collective meetings with all professors, the focus is often on product quality, yet mid-semester meetings sometimes reveal statements from professors regarding group performance and student conflicts. In this regard, the coordinator states, "...there are teachers with groups of students that separate more. We need training on how to manage conflicts with students, but it is also true that we do not know how to manage conflict among ourselves. So, it is difficult to expect teachers to support students in doing so" [P4].

Teachers generally understand the importance of teamwork but often struggle with their role in developing this competency. The course is structured around projects, and some Scrum tools are used to help students manage their teams and apparently achieve project objectives without much intervention from the teacher. However, few tools available allow for reflection on teamwork performance, which means there is no intentional focus on developing this competence. As a result, teachers may assume a range of positions, from passive observers to overly controlling, and students may not receive the scaffold necessary to develop their teamwork competencies. Recurrently, in interviews, teachers referred to their approach to teaching, where they are responsible for approving or rejecting students' work. Some teachers focus more on the outcome of the work, while others are more involved in managing the deliverable process. For example, P1 said, "I give instructions and then provide feedback on the final result." P2 said, "I set the conditions for the students to work, but I do not get involved in the process."

On the other hand, P3 emphasized the need for control in managing students' work, saying, "I think all teachers should handle the same scheme of managing the work of the groups. We should all ask them for memos of their meetings and check whether they are fulfilling their responsibilities." Overall, it is clear that teachers have different approaches to managing their students' work, with some focusing on the final result and others on team management regarding the deliverable process.

In addition, teachers have reported difficulties in establishing strategies for developing teamwork competencies during group professor meetings and individual interviews. As observed in the group meetings held twice a semester, teachers usually indicate that they have difficulties addressing the problems students face in their work groups. The professors refer to two situations that make teamwork difficult: students who are part of a group that does not get involved in the work of the "free riders" team and groups of students who approach the problems dealt with during the semester superficially. The action in front of these two situations varies according to how each teacher approaches the situation. In cases where the teacher cannot handle the situation, the program coordinator ends up intervening in the students who are not engaged [P4]. "Refer to my office the students who have problems that I talk to them to get them "aligned".". Generally, teachers express frustration with the student's motivation with the project and the management of conflictive teams: "There are irresponsible students who do not want to work with the project", "there are irresponsible students who do not want to work," or "I scare them so that they work well as a team" [P1]. In this type of statement, the limitations regarding the possibilities of action to mobilize the teams from a constructive point of view are evident.

Despite these concerns, teachers highly recognize the importance of developing this teamwork competency in students: "This competency is important for the working world but especially for engineering because this is developed in multidisciplinary groups." [P3]. Likewise, the teachers' conception of what teamwork means has several elements framed within the theories of teamwork conception that involve aspects of communication, coordination, individual and group responsibility for the task, and recognition of the objective, among others. In the conceptualization given by the teachers, there is little reference to the description of the type of interactions expected to occur during the evolution of the teams in the project. The underlying question is how the teacher conceives the teaching-learning process. The collection of evidence allows for visualizing an understanding of teaching in which the teacher is the one who delivers knowledge, and the student uses it under the teacher's supervision. For example, how does the teacher conceive the teaching-learning process?

In conclusion, the description of the initial situation allows evidence of two fundamental aspects that condition the development of teamwork competencies: first, the teacher's conception of the teaching-learning process and, within this framework, the transformative learning for the gain of autonomy by the student, and second, the formative intention of the activities developed in class and their alignment with the learning outcomes and specifically with the teamwork competency.

## 3.2 Imagined situation and pedagogical imagination

The imagined situation considers the solution to the challenges posed in the initial situation. On the one hand, it is expected that the teacher can generate a collaborative environment in the classroom, where the student experiences the design of a problem and its solution. In this process, the teacher must have the tools to accompany what emerges from the students' search, both related to the project's conceptualization and the elements of teamwork that are expected to be articulated. To this end, the teacher must question his role in the learning process from a vision centered on the student as the leading actor in the learning process and understand how the design thinking scheme of the course and the instruments used in class can enhance the development of teamwork competence.

Learning understood from the sociocultural view (Vygotsky, 1978) is a complex process product of the activity, context, and culture where it is developed and used. In this approach, the role of the teacher changes from one that presents information to one that designs and facilitates processes and designs learning environments that increase student engagement. The incorporation of projects in the curriculum is intended to bring students closer to complex problems, where they participate and approach the solution, involving not only knowledge but also their identity, meanings, and past experiences, having to contrast their frames of reference with other individuals and environments in the learning process. For this to happen, the teacher must shed his or her role of authority in class and empower students as actors in their own learning process. In discussions with the course coordination, observation and construction with teachers are proposed to generate tools and strategies that allow the mobilization of teachers towards the conceptualization of teamwork and its implementation in the classroom so that the teacher is reflective concerning how each of the course tools (Scrum, peer, and self-assessment, team contract, among others) can be used in the development of teamwork competence, taking into account the formative intentionality when using each tool.

With the observed teachers, it is agreed to reflect on what is being implemented in the classroom, in light of the conception of learning from the sociocultural vision of Vygotsky (1978), constructive alignment in teaching (Biggs, 2001) and cooperative learning (Jhonson & Jhonson, 2013). Intervention strategies are focused on accompanying teachers who have been observed. A reflective scheme is established and incorporated in classes that are accompanied every week or two. Teachers P1 and P2 begin to question themselves about the quality of classroom teaching based on questions asked at the end of each class session about their approach to learning. The questions aim to understand the teacher's vision of what is observed as teaching practice in the classroom and are generally associated with the teacher's formative intention with the development of the activities proposed for the class and the degree to which he/she perceives that he/she achieves that the students are learning. The initial questioning carried out in the interviews, and as a conclusion of the initial observations, presents us with a first moment where teachers express doubts about whether they are developing the competence in the students: "I thought I was developing the competence of working in teams, but now I wonder if the students do it and how they do it" [P2]. These types of dilemmas were observed in the case of teachers P1 and P2.

Regarding teacher P3, there were no significant inquiries about pedagogical practices or classroom change during the reflective conversations at the end of class. When asked about teaching-learning theories, teacher P3's concepts aligned with the theory: "Students are responsible for their learning, and my role is to motivate reflection in the teams". However, there were differences between the class dynamics and the theory. These differences were observed in class observations. During the presentation of a workgroup with difficulties in their organization as a team, the P3 teacher comments on the quality of the work done and the difficulties they are having as a team and invites them to reflect. Subsequently, he conducts a conversation with the work group where, after inquiring about how they are working, he tells them that they should present actions for improvement. When teacher P3 was asked about his formative intention aligned with the way of proceeding, no answers were found that would allow the initiation of more reflective questions. Interventions with this type of teacher may require more time due to the need to discuss particular topics and the limited availability of part-time teachers, so it was decided not to continue with the process of accompaniment with this teacher.

The initial observation exercise that was carried out with teachers P1 and P2 is just the starting point to support teachers in their transformation. The goal of the exercise is to encourage reflection that will lead to changes in the classroom, promoting collaborative learning through using explicit tools that facilitate teamwork. Together, teachers and students create a shared understanding of teamwork. Figure 1 shows how the course tools can support creating effective teams. The structure of the intervention is related to the dynamics of the classes. In the initial phase of the course, the primary focus is on fostering trust. In the second stage, the focus shifts to developing mechanisms for coordination and control. In the third stage, the emphasis is on conflict management. These stages are developed this way due to the students' needs throughout the course.

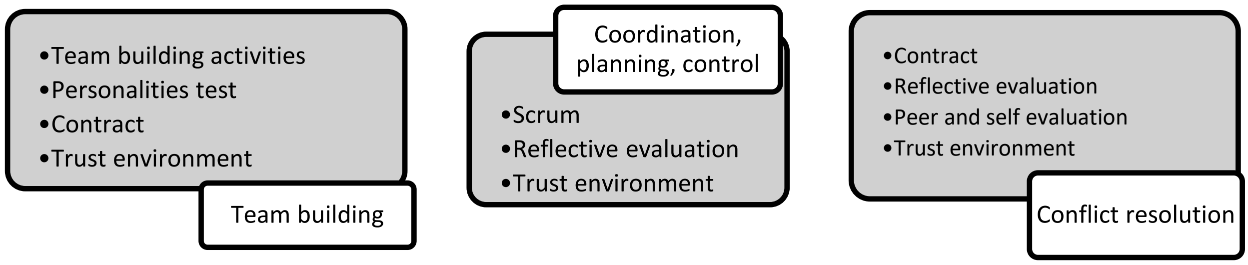


Figure 1. Classroom intervention strategies concerning the conceptualization of teamwork.

Two strategies have been established with the course coordinator: firstly, the training of all teachers to motivate the development of collaborative work competence among first-year engineering students. This involves transforming teaching practices to promote cooperation in the classroom and providing reflective support to teachers. Secondly, the professors will be accompanied throughout the semester to reflect on the teaching-learning process under a sociocultural vision and to assist in implementing the tools developed to generate student reflections on teamwork. In addition to training, the coordination seeks to schedule spaces to encourage the participation of teachers in reflection and the use of tools to develop teamwork competence. The intervention scheme of accompaniment agreed with the teachers for reflection is proposed according to Kolb's (1984) learning model, where the learning cycle has four stages: concrete experience, reflective observation, practical conceptualization, and active experimentation.

## 3.3 Arranged situation

This situation is based on a set of negotiations that consist of systematically addressing with teachers the strategies for implementing the tools that can be used to develop teamwork skills in the classroom. The strategy of using Scrum tools for reflection and the need for the evaluation to incorporate more elements of teamwork are presented to the course coordinator, who recognizes the importance of implementing the strategy.

At the beginning meeting of the semester, the plan for the use of the tools that the course provides for the development of reflections in students is presented. This meeting was intended to be aligned with the teacher training planned for the beginning of the semester. However, training does not take place until the middle of the semester because most of the professors are part-time, and there are crossovers regarding the availability of schedules. The training occurs in the middle of the semester, with five-course teachers and the coordinator. This presents a limitation in the ability to incorporate a new vision strategically in the semester's courses due to the limited number of attendees and the time at which it is carried out. Even though it was impossible to align this training with the accompaniment of teachers due to the disparity of the moments of conceptualization, this affected the vision of the teachers who attended. The professors expressed a new vision about their role in developing competence: "On the training day, I learned about the importance of developing teamwork competence. The course content is very focused on developing the design thinking methodology, and for me, the emphasis on teamwork was secondary. I used to see it as a marginal topic, and only on the training day carried out I recognized it was important". These kinds of comments show that the trainings facilitate the reflection of these issues among the teaching staff, which can be potentiated to promote the transformations of teachers concerning their pedagogical practices and reflective spaces in developing transversal competencies. Agreeing on spaces for intervention with the group of teachers becomes complex due to the difficulty that arises when coordinating meetings outside the workspaces.

The accompaniment scheme was carried out with P1 and P2 teachers following the Kolb learning cycle (1984). An example is the situation observed concerning incorporating the reflection strategy into the work carried out. After the first deliverable, P1 plans to reflect on the team's performance. The concrete experience, in this case, is based on the teacher's previous experience concerning applying the teamwork tools. In the planning conversation, the teacher says: "We are going to reflect on the work, but survey and reflection must be done as homework to save time in class." Reflective observation is generated by posing questions to know the intention and developing some activities during class. Abstract conceptualization is based on the answers given by the teacher, thus reinforcing the theory of constructive alignment (Biggs, 2001). Finally, in the moment of active experimentation, P1 expresses its intention to apply the tools in class: it applies the self-evaluation and co-evaluation tools. It shows the results in groups, delivers feedback on the work done, and then generates a space where the students discuss the results obtained in the partial evaluation and how they work as a team. As a result of this exercise, the contract agreement is modified according to group reflection. The teacher rotates through all the groups to listen to the reflections they make as a group. The groups actively discuss based on the inputs provided by the teacher. At the end of the class, there is a dialogue with the teacher about what was observed in the groups. After, some reflective questions are done. P1 reflects: "It was exciting to hear them talk. Some groups continue to have problems, but I think it is a moment where they can start discussing with their peers with objective tools… I think the results of this exercise differ from those they have when they do their homework at home. These are reflections that can motivate real changes in the team."

## 3.4 Exploratory reasoning

The situations presented present the need to transform the teacher's teaching practices, which should lead to the generation of collaborative environments in the classroom with greater student participation. This implies that teachers must be aware of the transformation processes beyond implementing tools in the classroom. From Merizow's perspective of transformative learning (1997), transformation implies a change that involves integrating what has been learned into the daily routine of teaching practice. This is one of the main challenges in transformation because it implies the teacher's agency to reflect on their practice and act towards incorporating strategies that begin to be part of their identity. This shift is evident in the narrative of the P1 teacher, who considered the reflection of teamwork as a secondary component of his teaching. However, after training and hands-on experience, your perspective changes radically. P1 perceives the importance of actively engaging students in reflecting on their teamwork, recognizing that these reflections can motivate significant changes in team behavior. This change in the perception and pedagogical practice of the P1 teacher reflects a process of educational transformation according to Mezirow's theory. From the perspective of developing teamwork competencies, the P1 teacher demonstrates a progression in his ability to facilitate collaborative learning and reflection among his students. Initially, I plan to have students reflect outside the classroom to save time. However, as the process progresses and she actively experiments with applying tools such as self-assessment and in-class feedback, she recognizes the value of taking time in the classroom for students to reflect and discuss together. This change in the P1 practice indicates progress towards actively promoting collaborative learning and the development of teamwork competencies in students. Likewise, in the example, P1 proposes a change towards incorporating the tools as an element that promotes student reflection from a disciplinary perspective and the way interactions occur in the classroom.

Finally, although it is not possible to evidence the pedagogical transformation of the rest of the group of teachers, it is observed that it is possible to generate a disorienting dilemma based on training that leads to the permanent reflection of the teacher. Teachers are willing to reflect on what happens in the classroom because they understand their responsibility to train professionals. According to the information collected, there are two barriers in the process of implementing changes in the classroom: on the one hand, the change in the level of authority in the class, granting power of action to the student, and on the other hand, the lack of conceptualization regarding the teaching of competencies such as teamwork.

# 4 Conclusions

The pedagogical transformation for the development of teamwork competencies implies a conceptualization of collaborative learning by teams, where the student is the one who takes action in their learning process. Part-time teachers say they do not have time to implement substantial changes in their subjects. However, by addressing situations reflectively, they naturally begin to change their teaching practice. This ends up being an example replicable to their own practice, where it is observed that there is beginning to be a transition towards practices that are less focused on the teacher.

Several tools can be used in the course with a formative intention associated with developing teamwork. How to articulate them to develop competencies depends on the teacher's vision of teaching, which can take them as tools that the student must learn to use or tools that allow team management as a final goal.

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# PAEE/ALE’2024 Workshops and Hands-on sessions

Submissions accepted for the PAEE/ALE’2024 hands-on sessions.

# Workshop: Active Learning Teaching Methods for Engineering Ethics Education

Shannon Chance[1,2]

[1] School of Architecture, Building & Environment Research (SABER), Technological University Dublin, Dublin, Ireland
[2] Centre for Engineering Education (CEE), University College London, London, United Kingdom

Email: shannon.chance@tudublin.ie, s.chance@ucl.ac.uk

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**Abstract**

This workshop, conducted by the lead editor of the forthcoming Routledge International Handbook of Engineering Ethics Education, focuses on exploring active learning teaching methods in engineering ethics education. Beginning with a whole-group discussion to define ethics in engineering education, facilitators will present an overview of trends and teaching methods outlined in the handbook. These methods include case studies, project-based learning (PB), value-sensitive design, service-learning, arts-based methods, and reflective and dialogical approaches. Participants will then engage in hands-on activities, selecting one ethics topic (e.g., environmental sustainability, social justice, equity, diversity, and inclusion) and one active learning pedagogy (case studies and dilemmas, PBL, or reflective approaches) and explore their integration into one of their programs or modules. The workshop aims to familiarize participants with the handbook, promote its utility for educators, and provide a platform for understanding and applying concepts from its chapters. Participants will work collaboratively to identify ethical issues and apply chosen methods to engineering modules, fostering critical discussion, and planning for ethical integration. By the end of the workshop, participants will be able to define ethics in engineering education, recognize various ethical issues, identify active learning methods for teaching ethics, describe plans for integrating ethics into modules, evaluate proposed activities, and understand the content of the forthcoming handbook. This workshop aligns with conference themes on active learning, innovative experiences in engineering education, and ethics and sustainability.

**Keywords**: Active Learning; Engineering Education; Ethics; Teaching Methods.

## 1 Introduction

The facilitators of this session are authors of the "International Handbook of Engineering Ethics Education," to be published by Routledge in 2024. The handbook covers six themes – Foundations of engineering ethics education, Interdisciplinary contributions to engineering ethics education, Ethical issues in different engineering disciplines, Teaching methods in engineering ethics education, Assessment of different aspects of engineering ethics education, and Accreditation and engineering ethics education. This workshop focuses on one of these themes: **Teaching methods in engineering ethics education**.

The workshop will start with a whole-group discussion, identifying the meaning of "ethics" in engineering education. Then the facilitators will provide a brief overview of trends and ways forward to support engineering ethics instruction, followed by a brief definition of each of the six teaching methods covered in the book: case studies, project-based learning (PBL), value-sensitive design (VSD) and design-based learning (DBL), service-learning and humanitarian engineering education, arts-based methods, and reflective and dialogical approaches. The facilitator has taught using all the active learning approaches covered, and her overview slides will include images illustrating her own applications.

Most of the workshop time will be spent applying the methods; each participant will select a method they would like to explore from the standpoint of integrating **engineering ethics** into their programs or modules.

The facilitators' motivations for this workshop/hands-on session are to build participants' familiarity with the forthcoming handbook, to promote the handbook as a helpful tool for educators, to give educators a chance to understand and apply concepts from the various chapters, and to provide a focused time for everyone at the PAEE/ALE conference to focus on ethical issues for an hour.

This workshop relates directly to one of the following conference themes:

- Experiences in Active Learning and PBL in engineering education
- Innovative experiences in engineering education
- Ethics and sustainability in engineering education

## 2 Activities

Each participant will select one of the six proposed teaching methods and join a group dedicated to exploring that method. Each group will receive a handout about the method to use as a guide. Once the groups are assembled, the facilitators will ask each group to identify an ethical issue they would like to develop together and an engineering module within which they would like to apply. As they work collaboratively, they can define the module broadly (e.g., mathematics, chemistry, thermodynamics, statics and strengths of materials, bridge design, or a dedicated ethics module for engineers).

Learning outcomes are as follows. At the end of this workshop, participants will be able to:

- define what ethics means in the context of engineering education,
- identify/name a range of issues relevant to engineering ethics education,
- identify/name a range of active learning methods used to teach ethics in engineering,
- describe a plan for using one of the recommended teaching methods to integrate a new/additional aspect of ethics into one of the modules they teach,
- critically evaluate and discuss activities proposed by others for integrating ethics using active learning methods, and
- describe the forthcoming handbook and identify/name some of the topics covered in it.

The primary literature supporting this workshop is by Polmear et al. (forthcoming), Herzog et al. (forthcoming), Routhe et al. (forthcoming), Gammon et al. (forthcoming), Daniel et al. (forthcoming), Hitt et al. (forthcoming), Marin et al. (forthcoming). The facilitators will draw from their reading of the pre-prints of these chapters.

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# Workshop: The Inclusion of Technology and Sustainability in Engineering Education - a Realistic Approach

Miguel Romá[1]

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

Email: miguel.roma@ua.es

DOI: https://doi.org/10.5281/zenodo.14062916

**Abstract**

In the context of engineering education, it is mandatory to make students think about the impact that technology has on many aspects of life. We, as engineers, and our students as future engineers, must be aware of both the kind and detrimental effects of technology from the widest possible range of viewpoints. Issues such as the management of technological waste (related to planned obsolescence), the risk of generating unemployment caused using technology (automation and robotics), the relevance of having a strong technology industry to sustain our working environment, the relationship between sustainability and renewable resources..., are clear examples of aspects suitable for generating interesting debates. However, there is a key element that is usually left aside because it leads to uncomfortable conclusions: can we talk about sustainability without thinking about the effects of economic growth? In this hands-on session we will present an activity used to promote critical thinking in students about the relationship between technology, economic growth, and sustainability. We will try to present the most common thoughts when technology, energy, sustainability, and growth are put in the same container. In the workshop we will analyze whether or not sustainable development is compatible with economic growth and the consequences derived from this analysis.

**Keywords:** Active Learning in Engineering Education; Sustainability in Engineering Education; Critical Thinking in Engineering Education.

## 1 Introduction

We, as educators, expect engineering students to be aware of the future as a global issue. In fact, students explicitly want to discuss about ethic and sustainable development in engineering and engineering education, as conclude in the Board of European Students of Technology Symposium hold in Madrid in 2006 (BEST, 2006). Anyway, we can introduce elements closely related with the engineering framework to generate the appropriate working environment to think actively and critically about the future. The relationships of technology and sustainability, renewable energies and lifestyle, economic growth and ecologic waste management and, in general, the role of Engineers and Engineering in the consecution of a 'friendly' future are topics relevant enough to be taken into account in the engineering education process.

There is a real debate about whether the complexity of current problems is so great that a reliance on technical solutions alone is unrealistic. Nevertheless, the engineer in his or her professional role will still rely on applying technical solutions to problems such as energy provision and adaptation to climate change (Fenner et al. 2006). The problem is more complicated than it may appear at first sight, since, on the one hand, there are misconceptions in the relationship between sustainability and educational organizations (Ramírez, 2012) and, on the other hand, the concept of sustainable development of a high percentage of students is very superficial, limited to aspects such as recycling or Earth Hour (Sheikh et al. 2012). In addition, the conclusions obtained in a previous workshop (Romá & Martínez-Marín, 2016) showed that the simplified perception of the concept of sustainability is also supported by (some) engineering professors. Even some of them were reluctant to accept the information provided by scientific data to maintain their previous ideas.

The proposed activity is very similar to the one the author proposes to senior telecommunications engineering students in a session of a subject not focused on sustainability, as a way to introduce the topic in a curriculum without sustainability courses. The proposal presents two different levels. On the content side, we propose to discuss about sustainability, future, economic growth, technology, and the role of engineers in this puzzle. The second level of the activity will explore the effects of confronting one's mind scheme against facts that may (or may not) fit well in this structure. Usual reactions can be to deny the facts, re-interpret the facts to make them fit with the mind scheme so this scheme will be stronger or to make tremble the mind scheme. At first sight, the discussed questions may seem simple, but the pack formed by economy, environment and society is a very complex dynamic system. The fact that the system is dynamic is one of the key elements justifying the interest of making students think about these concepts. As stated in Booth-Sweenwy and Sterman (2000), highly educated subjects with extensive training in maths and science have poor understanding of some of the most basic system dynamics, because of some tests with students at the MIT Sloan School of Management.

## 2 Activities

There are many contributions analysing the factors affecting sustainability. The funny part is that it is possible to find the same factor considered as an element that will and will not ensure sustainability. Ecologists, economists, engineers, or scientists show very different points of view polarized by their academic profiles. For instance, while ecologists clearly rely on renewable energies as the key element for sustainability, (Cheng, 2015) clearly states that renewable energy will not be able to replace fossil fuels, and the work by Adair (2010) points out that the installation, operation, and maintenance of renewable plants needs fossil fuel questioning the sustainability of renewable energies. In this sense, the evolution (and future projection) of energy production is used as a key argument. Nowadays the energetic efficiency of renewable sources cannot be compared to that provided by fossil fuel.

Even general people without specific knowledge can also defend very different positions depending on their mind model. One of the most found positions is that based on the hope that technological improvements will be able to manage energy-related issues. In this sense, as pointed out in Tlusty, (2015) influencing people, as the General Electric CEO Jeffrey Immelt claimed that *for achieving sustainability, technology is the only answer*. A curious aspect highlighted in this work is that, in almost all the cases, when technology is apparently used with sustainability goals, the reality is that these technological improvements, under the tag of *restorative technologies*, their real mission is to reduce our impact on the planet caused by older technological developments.

The main goal of the session will be to explore the initial position regarding this topic and confront it with analytical information that can be easily handled from an engineering profile. It is recommended reading Nevel et al. (2024) (available online, the link is provided in the reference section).

To avoid the possibility of generating different ideas from those previously owned by the attendants to the proposed session, we will advance just an overview of the kind of activity that will be performed, as it is important to allow each participant to present his or her ideas about the topics presented. Moreover, as there are many possible different ideas, it is impossible to know in advance how the session will evolve. The attendees will be divided into small working groups. Basically, the session will consist of five stages:

1. Topic presentation. The complexity of sustainable development will be introduced.
2. Search for a consensus definition of sustainable development. In the academic literature, it has been estimated that there are over 300 definitions of sustainability and sustainable development (Jonston, P., Everad, M. & Santillo, D., 2007), so it is compulsory to state a unified starting point.

3. Each group will be assigned a dimension (population, energy, food, environment, economy, society) to analyze whether the definition of sustainable development is met as if they were independent variables, and to determine the role of technology in ensuring sustainability for the assigned dimension.
4. Confrontation of ideas with data. Information (real data) related to the exponential growth, economy and ecology will be presented.
5. Final thoughts.

The final part of the session will be used to conclude the key elements considered to be able to ensure sustainability and how these factors will affect to our future life. We will also analyse how these ideas can be fitted in our mind model. A parallelism with '*Psycohistory*' (a fictional science in Isaac Asimov's "Foundation" book which combines history, sociology, and mathematical statistics) will be tried.

# 3 Expected results

As we are proposing a hands-on activity, its conclusion cannot be presented until the realization of the activity itself, so this section presents just as an outline, the main ideas we expect to debate. The starting point will necessarily be to share a definition of sustainable development.

We expect that, after the session, attendees will have a technically sounding vision of sustainability that may provoke some discomfort. We will discuss about the future from an economic point of view and the role of technology and energy to ensure a sustainable future. We will introduce the concept of economic growth in the equation and a discussion about economic growth and sustainability will follow (Higgins, 2013).

Due to the engineering profile of the attendees, the role of technology in the puzzle formed by society, economy, and environment can be used as an entrance to the sustainability problem.

We will explore if the initial mind model has or not been affected with the inclusion of new data. We will assess the interest of carrying this activity with attendees' students. We will study the possibility of exporting the idea of mind model confrontation to the attendees' areas.

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# Workshop: AI - ally or enemy for engineering learning?

Miguel Romá, Pau Bofill[2]

[1] Group of signals, systems and telecommunication – SST. University of Alicante, Spain
[2] Universitat politècnica de Catalunya – Barcelona Tech, Barcelona, Spain

Email: miguel.roma@ua.es, pau.bofill@upc.edu

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**Abstract**

The last few years have seen the irruption of artificial intelligence for a multitude of applications. The speed of development of such applications has been faster than the speed of adaptation to them in the field of university education. Given this fact, the question arises as to whether to prohibit the use of AI by students as their learning may be negatively affected (something equivalent to cheating) or to allow (or promote) its use. In the first case it is possible that students will use AI and try to hide it. In the second case, it will be necessary to adapt the learning activities so that their outcomes are not compromised. In the proposed hands-on session these issues will be discussed as well as how to approach the design of learning activities that reinforce learning by promoting the use of AI tools.

**Keywords:** AI in engineering education; Active learning in engineering education.

## 1 Introduction

In the ever-evolving landscape of education, it is incumbent upon us as educators to adapt our teaching methodologies to meet the needs and expectations of the next generation of engineers. As we witness the transformative power of Artificial Intelligence (AI) across various domains, it becomes imperative for us to explore its potential applications in engineering education. The forthcoming workshop serves as a platform for us to collectively delve into this crucial intersection and strategize on how we can leverage AI to reinforce and enrich students' learning experiences.

The objective of this workshop is not merely to introduce AI as a novelty in our classrooms but rather to comprehensively examine how AI tools and techniques can be seamlessly integrated into our pedagogical approaches to amplify student engagement, comprehension, and retention of engineering concepts. Through collaborative discussions, interactive sessions, and hands-on demonstrations, we aim to equip the participants with the knowledge, resources, and strategies necessary to effectively harness AI for the betterment of engineering education.

Allowing engineering students to use AI tools for their tasks comes with several strengths and potential dangers:

**Strengths**:

1. *Efficiency and Productivity*: AI tools can automate repetitive tasks, allowing students to focus more on problem-solving and creative aspects of engineering projects.

2. *Enhanced Learning Experience*: By using AI tools, students can gain hands-on experience with cutting-edge technologies relevant to their field.

3. *Personalized Learning*: AI tools can adapt to individual learning styles and preferences, providing personalized feedback and recommendations to students.

4. *Access to Advanced Technologies*: This democratization of technology can level the playing field and empower students from diverse backgrounds.

5. *Fostering Innovation*: By leveraging AI tools, students can explore innovative solutions to complex problems and push the boundaries of traditional engineering practices.

**Dangers**:

1. *Overreliance on AI*: There is a risk that students may become overly dependent on AI tools, relying on them to perform tasks without fully understanding the underlying principle.

2. *Bias and Ethics Concerns*: AI algorithms may inherit biases from the data they are trained on, leading to biased outcomes or decisions. Moreover, the ethical implications of using AI in engineering tasks, such as privacy concerns or unintended consequences, need to be carefully considered and addressed.

3. *Skills Gap*: Depending too heavily on AI tools without developing foundational engineering skills could result in a skills gap among students.

4. *Security Risks*: AI tools may introduce security vulnerabilities or privacy risks, particularly if they involve handling sensitive data or interacting with external systems.

5. *Loss of Creativity and Innovation*: While AI can facilitate innovation, there is a concern that it may also stifle creativity by limiting the diversity of solutions explored or by imposing constraints based on existing data patterns.

Overall, while the integration of AI tools in engineering education offers numerous benefits, it is essential to approach their use thoughtfully and mitigate potential dangers through proper guidance, ethical considerations, and a holistic approach to learning. This is, in essence, the main objective of the proposed workshop.

According to Mhlanga (2023) “the use of ChatGPT in education requires (…) transparency in the use of ChatGPT”, so it is fair to admit that the above text, as a sample of the potential of using AI tools, was mostly written in response to a single ChatGPT prompt. Strength number 1 is obvious, both in terms of time efficiency and writing style (which is a major effort for people for whom English is not their mother tongue). However, although we do not have concrete data, the first appreciations about the impact of the use of this tool by students generate certain problems, especially the lack of reflection, due to the immediate obtaining of results, and, more importantly, the loss of learning opportunities by not having to face the search for error solution inherent to the problem-solving process.

It may seem reasonable to decide in a thoughtful way, what access to AI there should be for engineering education in the future (actually, already in the present). According to Cárdenas (2023) we can think in, to simplify, four scenarios (Figure 1).

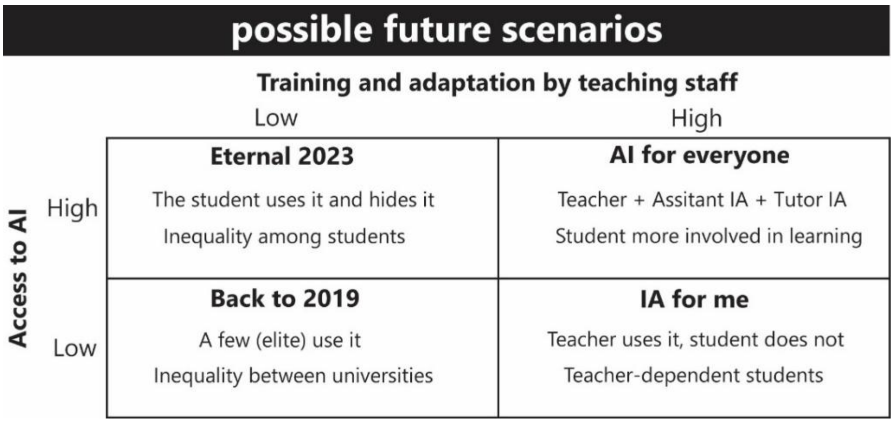


Figure 1. Possible future scenarios about the use of AI in education.

Although the risks of regenerative AI have been identified in several studies, such as Cain (2023), Moloi et al (2023) or Qadir (2023), the solution does not seem to be to prohibit its use. Moreover, we know without a doubt that its use is widespread among students. Trying to prevent its use makes the same sense as thinking that a calculator or a spell checker could be banned. In addition, as has become clear from the beginning of this introduction, educators use generative AI to, among other things, increase productivity.

Here's what you can expect from this workshop (also generated by chatGPT):

**Designing AI-Enhanced Learning Activities and Assessments:** we will delve into the practical aspects of designing AI-enhanced learning activities and assessments.

**Addressing Challenges and Ethical Considerations:** As with any technological innovation, the integration of AI into engineering education presents its own set of challenges and ethical considerations. We will facilitate discussions on topics such as data privacy, algorithmic bias, and the ethical use of AI, empowering you to navigate these complexities and cultivate a responsible AI culture within your classrooms.

**Fostering a Community of AI-Enabled Educators:** Finally, this workshop serves as an opportunity for you to connect with fellow educators who share a passion for leveraging AI to enhance student learning in engineering. Through collaborative brainstorming and networking, you will have the chance to exchange ideas, share best practices, and forge meaningful partnerships that extend beyond the confines of this workshop.

## 2 Activities

As stated in the introduction, the objective of the workshop is to discuss, explore and analyse the potential risks of generative AI as a tool for learners and to seek strategies to minimize such risks in the design of learning activities that strengthen learning outcomes. Attendants will be arranged in small groups making emphasis in forming teams with people with different background. The session will be organized as follows:

- Topic presentation.
- Warm-up activity.
- Risk identification.
- Search for activity design strategies.
- Discussion.
- Conclusion.

As the discussion on the responsible and ethical usage of ChatGPT in education has been encouraged (Mhlanga, 2023) a special focus will be placed on this extremely important topic. **Participants must provide a laptop or cell phone**.

## 3 Expected results

After the workshop, it is expected that attendees will have a clear idea of the potential risks of AI in their respective courses. It is also expected that they will have come up with activity design strategies to minimize such risks. It will be interesting to know if participants find the proposal interesting enough and to listen to their comment to make the activity more interesting and productive for possible future editions.

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# Workshop: Collective construction of a course on Peace Engineering syllabus from an interdisciplinary dialogue

Alexei Ochoa-Duarte[1], Leonardo León[1 2]

[1] Universidad Nacional de Colombia, Bogotá, Colombia
[2] Colegio Atenas, Bogotá, Colombia

Email: agochoad@unal.edu.co, alleonr@unal.edu.co

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**Abstract**

Engineering and technology for peace have had little theoretical development despite the existence of multiple initiatives in academic practice and intervention in this area. To contribute to fill this gap, the Research Group on Technologies and Innovation for Community Development (GITIDC in spanish) has been working on a research project, funded by the German-Colombian Center for Peace (CAPAZ in spanish), entitled "Engaged Engineering and technologies for peace in Colombia. Reflections, practices and future(s)". For the execution of the project, initially, information was collected from different sources, which included a literature review, three discussions with actors who have been working on the issue of Engineering and Technology for Peace, thirteen interviews with experts in this area and four workshops for the participatory design of a subject on engineering and peace. From the discussions generated by the activities, contributions have been made that are aimed at the conjunction between theory and practice to strengthen the proposals of engineering for peace, elaborating the program of a course on engineering and peace that is being developed as a pilot test at the Universidad Libre - Seccional Cali in Colombia. Additionally, we have thought of strategies to disseminate the results that go beyond the participation in academic events and the writing of articles that synthesize the results, including the design of a set of cards (postcard type) to show each of the experiences interviewed and the elaboration of a web page. In order to make the course known and continue the collective construction of the course, it is proposed to develop a virtual workshop at the international level to nurture the contents of the subject, as well as the structure of the course.

**Keywords**: Engaged Engineering; Engineering Education; Peace Engineering; Peace Studies.

## 1 Introduction

In order to talk about Peace Engineering, it is important to revisit the origins and development of engineering as a function of war (Riley, 2008), as well as the alternative proposals and praxis (Ochoa-Duarte, 2024) for the construction of peace for humanity, in general, and for communities historically affected by war, in particular.

Peace engineering and technology have been little theoretical, although there are several initiatives in academic practice and the field is being addressed (Reina-Rozo, 2020; Kleba & Reina-Rozo, 2021). To fill this gap, the Community Development Technologies and Innovations Research Group (GITIDC in Spanish) (Reina-Rozo & Ochoa-Duarte, 2021) worked on the research project "Engaged Engineering and Innovation and Innovation Technologies for Peace in Colombia Reflections, practices and the future" funded by the German-Colombian Peace Center (CAPAZ in the Spanish).

Its objectives are, to describe and expand the field of Engineering and Engineering Education for Peacebuilding in a Latin American scenario; to analyze experiences in Engineering and Technology for Peacebuilding in Colombia; and to propose spaces for training at the institutional level in "Engineering for Peacebuilding" within the framework of the Colombian Network of Engineering and Social Development (ReCIDS in spanish) (Salcedo, Vega & Reina-Rozo, 2021).

Initially, we collected information from various sources, like a literature review, three discussions with stakeholders who worked on Peace Engineering and Technology, thirteen interviews with experts in the field, and four participatory workshops to create a peace engineering course syllabus (Ochoa-Duarte & León, 2023).

We found discussions from different ideological sides, as well as works that contribute to the construction of peace from practice, taking the definition for granted. The synthesis of the results can be found in the project's website (Ingeniería, Tecnología y Paz, 2023).

From this work, it was determined that the course Peace Engineering and Technology in Colombia is an interdisciplinary course that seeks to discuss the role of science, technology and engineering both in the promotion of conflicts and in the search for peace, in order to contribute to the construction of critical thinking among engineering students and other areas through reflection/action, that is, through reading, writing, group discussion and prototyping of solutions. The objective of the course is to make an introduction to the field of engineering for peace through reflections-actions around the role it has played and should play in Colombia, from a historical point of view, discussing current initiatives and possible future paths.

Table 1 below shows the proposed contents of the course. It is important to mention that this course has a theoretical-practical character that can be observed in the topics covered and in the realization of field work and a prototype.

Table 1. Course schedule.

| **Week** | **Topics** | **Week** | **Topics** |
|---|---|---|---|
| 1 | What kind of peace are we talking about? Positive peace and negative peace.<br>Presentation of the course program. | 9 | Engineering and *Buen Vivir*: other possible engineering.<br>Prototype design. |
| 2 | History of engineering and its relation to war.<br>Presentation of the problem bank. | 10 | Engineering for sovereignty (environmental, social, political, food, technological).<br>Prototype design. |
| 3 | Ethics, action without harm and engineering.<br>Problem choice. | 11 | Social technologies for peace.<br>Prototype testing. |
| 4 | Engineering, development and its victims.<br>Field trip. | 12 | Experiences of peace engineering in the world.<br>Prototype validation. |
| 5 | Engineering and social injustice.<br>Rapid prototyping workshop. | 13 | Peace Engineering experiences in Colombia.<br>Prototype improvement. |
| 6 | Engineering and environmental injustice.<br>Understanding of the chosen problem | 14 | The role of science and technology in peace agreements.<br>Implementation budget. |
| 7 | Engineering and social justice.<br>Prototype design. | 15 | Alternative (Engaged) engineering networks.<br>Social appropriation of technology. |
| 8 | Engineering and sustainability.<br>Prototype design. | 16 | Presentation of prototypes and articles. |

A pilot test of this course was conducted within the framework of the Social Projection in Engineering course at the *Universidad Libre - Seccional Cali*, during the second semester of 2023. This first scenario, developed virtually, and lasting 1 hour per week throughout the semester, was supported by a professor who is part of ReCIDS, and allowed his students to make discussions, debates and didactic materials (infographics and videos) to meet the learning objectives of the subject. However, the virtuality and the length of the classes were considered as barriers to the teaching-learning processes. Asking to the students at the end of this course, they agree that it was successful in terms of discussions and results. In addition, they highlight the importance of addressing these issues of engineering and peace from the early stages of their engineering education.

Nevertheless, this experience allowed the opening of other scenarios such as forums, conversations, public policy discussions and specialized publications in other Colombian universities. Such is the case of the participation as guests of the subject Engineering and Society of the *Universidad del Valle* - Palmira branch, in the *Agenda Regional en Educación para que florezca la Paz* of Universidad de Caldas, in the IV Colombian Meeting of Engineering and Social Development, held in Pereira by the Colombian Network of Engineering and Social Development (ReCIDS in spanish) (Ochoa-Duarte and León, 2023). In addition, the creation of the subject Engineering and Peace has also been attempted at the *Universidad Nacional de Colombia* - Medellín, through the *Instituto de Educación en Ingeniería* (IEI). However, it has not been possible yet.

Also, we propose a definition of Peace engineering that includes both theoretical references and collected data from different experiences. In this sense, this definition becomes a starting point to strengthen both theory and practice in the field of peace technologies, initially in the Colombian context, but can be used to promote new research in other contexts. In this sense, Peace engineering is the application of science and technology in pursuit of collective well-being, socio-environmental justice and social appropriation of technoscience, contributing to the mitigation of direct, structural and cultural violence through technological co-production with the communities involved, in active learning environments. In addition, we considered strategies for disseminating findings that go beyond attending academic events and writing articles synthesizing the findings, including designing a set of (postcard-style) cards showing each interviews' experiences and a website (Ingeniería, Tecnología y Paz , 2023).

## 2 Activities

In order to make the course known and continue the collective construction of the course, it is proposed to develop a virtual workshop at the international level to nurture the contents of the subject, as well as the structure of the course. This workshop is oriented to all the people interested in collaborating with the design of the Engineering for Peace course. In this way it is perfectly aligned with the themes of the conference and allows the creation of collaborative networks to strengthen Engineering for Peace.

On the other hand, it is important to mention that no other workshop or special session with a similar theme was found. This also gives more importance to the proposal to be part of the conference. Additionally, workshop participants are members of GITIDC, have explored the topic, conducted interviews and have written an article in which they propose a definition of Peace Engineering.

The methodology of the workshop will consist of collaborative work that will be conducted online, in which the starting point will be discussion-provoking questions that allow both reflection and proposal. A collaborative work platform will be shared, where the different opinions will be posted, first in a general way and then organized in the form of a tree or mind map,

A similar version of this workshop has been done four times. The first was the construction of the engineering and peace course program itself, which was carried out virtually with experts on the subject. The second was a workshop held within the framework of the *Agenda regional en educación para que florezca la paz*, held at *Universidad de Caldas*, in Manizales. The third, was a virtual class that was given to students of an engineering subject at *Universidad del Valle*, Palmira campus. And the fourth, was a workshop in *Tercer Coloquio Tecnología y Sociedad* organized by ReCIDS at *Universidad Nacional de Colombia - Medellín (*Ochoa-Duarte y León, 2024), which was very similar to this event, in which we worked mixing group work with general discussion, avoiding any group dispersion.

The provocative questions are: What content and methodology should an Engineering for Peace course have, what voices should be in an engineering and peace course, and how are they actively incorporated in the process? And what results would be expected from an engineering and peace course, both in terms of learning outcomes and in terms of academic production and impact on a territory?

# 3 Expected results

It is expected that at the end of the workshop the participants will recognize the importance of building peace engineering in a collective way, and that through the reflection developed in the workshop, they will begin to encourage this type of engineering in their daily activities.

It is also expected that the course program will be strengthened through the dialogue carried out in the workshop.

Additionally, it is expected that the participants will be aware of the need to strengthen peace engineering and promote experiences that explore this topic in their institutions.

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# Workshop: Development of Competency-Based Curriculum

Luciano P. Soares[1], Fabio Orfali[1]

[1] Insper Instituto de Ensino e Pesquisa, São Paulo, Brazil

Email: lpsoares@insper.edu.br, fabioo1@insper.edu.br

DOI: https://doi.org/10.5281/zenodo.14062941

**Abstract**

The development of a curriculum for an engineering program is always challenging as it needs to identify and address competencies that are indeed relevant for the future engineers. While engineering programs typically emphasize technical skills, competencies such as communication and teamwork are currently considered equally vital. It is important to ensure that all planned competencies are properly spread out over the student's years of education and given enough attention across different classes. The primary goal of this workshop is to tackle the challenge of balancing competencies across the various courses within an engineering program, ensuring that each course adequately covers its designated competencies. Additionally, we will explore how competencies can be effectively broken down to understand and evaluate skills, knowledge, and attitudes. We'll briefly discuss teaching methods and explore potential learning strategies with workshop participants. Furthermore, we'll address the process of writing learning objectives or outcomes for a course syllabus and close the loop by verifying whether the set of courses is indeed adhering to the program's proposal to proportionally empower students with a defined set of competencies.

**Keywords:** Curriculum Development; Competency Balancing; Learning Objectives.

# 1 Introduction

Engineering has been facing increasingly significant challenges in recent decades, such as sustainability and the fourth industrial revolution, which demand a new profile from Engineering programs' graduates (Hadgraft & Kolmos, 2020). Addressing these new challenges goes far beyond the traditional image of engineers' technical tasks and responsibilities, requiring a type of engineer capable of understanding the economic, social, and environmental contexts in which problems are embedded, and who can work both within and outside the boundaries of their own discipline (Van den Beemt et al., 2020).

Given this scenario, it becomes essential to reflect on strategies for developing Engineering curricula that foster competences beyond the technical in students, in order to prepare them to address contemporary complex problems. This reflection is even more timely considering that, for a long time, the course creation process in Engineering programs was based on the content to be taught, rather than on the skills to be developed (Orfali & Vieira, 2023).

Despite the growing interest in the integration of general competencies, also referred to as soft skills, into Engineering curricula, there is still no consensus on the best approaches to teach and assess them. However, certain insights are recurrent across many studies on the subject. According to Caeiro-Rodríguez et al. (2021),

It is generally accepted that soft skills cannot be learned passively, as raw knowledge acquisition. Students need to adopt an active role where they can experience their capabilities, strengths, and weaknesses in relation to soft skills (p. 29223).

Considering the challenge of integrating general competencies into Engineering curricula and the role of active learning in this process, the primary objective of this session is to equip participants with educational tools for developing an engineering curriculum grounded in active learning strategies.

Next section outlines how this objective is intended to be achieved.

## 2 Activities

The session aims to offer participants strategies based on frameworks that organize competencies within an engineering program, thereby assisting in tackling the challenge of balancing competencies across various courses throughout the program's duration. The overarching goal of this process is to ensure that each course comprehensively covers its designated competencies. Additionally, the tools presented can be employed to dissect competencies to evaluate skills, knowledge, and attitudes across the engineering program.

We will also explore the process of formulating learning goals or outcomes for a course syllabus. Furthermore, we will ensure alignment by assessing whether the array of courses aligns with the program's proposal, thereby empowering students proportionally with a defined set of competencies.

The planned activity involves developing a fictitious engineering program. We will guide participants through each step using the proposed frameworks and facilitate discussions to share concerns, ideas, and strategies.

This workshop draws upon Insper's experience (Soares, Achurra & Orfali, 2016) with curriculum development for three engineering programs in 2014. This process was supported by the Olin College of Engineering (Miller, 2019; Somerville, 2005), which also has extensive experience in engineering program development.

### 2.1 Competencies for an Engineering Program

During the initial segment of the workshop, participants will design a hypothetical undergraduate program. Their task will be to identify the primary competencies that students should develop to become engineers. Balancing these competencies presents a significant challenge, as program coordinators in engineering education often highly prioritize technical skills. However, contemporary demands require the inclusion of general competencies, emphasizing the need for careful planning and adequate student time allocation for the development of each competence.

### 2.2 Competencies for a Course

The second part of the session is more focused on exploring a specific engineering course, with an emphasis on identifying and crafting learning goals for that course. This segment may spark interesting discussions, as creating effective learning goals is both challenging and crucial. Subsequently, participants can discuss various learning activities that align with the desired competencies and learning goals. The planned activity will prompt participants to brainstorm several learning strategies, which they will then classify as classical, innovative, or somewhere in between. Moreover, these learning strategies should be clearly linked to teaching specific competencies, along with indicating the intensity with which each activity is used to teach those competencies.

### 2.3 Assessment for a Course

The final step in this process is to verify whether the learning goals align with the assessment, which, in turn, align with students' learning experiences. This alignment is crucial for identifying essential aspects of a course and discerning others that may be unnecessary. To facilitate this process, we will briefly cover rubrics. Rubrics are powerful tools for evaluating students, but they can be challenging to create and complex to use during the evaluation process. Various formats and approaches exist for writing rubrics, but the main goal is to ensure they are easily understood by both students and evaluators, reducing subjectivity regarding learning goals.

## 3 Expected Results

The expected results are for session participants to become familiar with tools that can assist in developing new engineering programs. This session is not intended to deeply explore any of the tools covered, but rather to present and briefly discuss tools that can be utilized for creating engineering programs. One advantage of using these documentation tools is that they facilitate discussions with faculty and school administration. After, throughout the program implementation, the planned goals can be monitored and adjusted as necessary.

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# Workshop: How to Plan an Interdisciplinary Project-Based Learning (PBL) Approach

Rui M. Lima[1], Diana Mesquita[2]

[1] ALGORITMI / LASI 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: rml@dps.uminho.pt, dmesquita@ucp.pt

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**Abstract**

This workshop aims to support participants to be able to plan an interdisciplinary Project-Based Learning (PBL) approach, exploring several dimensions of PBL. The conceptual fundamentals, such as framing PBL in the Active Learning continuum, PBL principles, project typologies, and PBL models, will be briefly discussed, serving as a basis for the workshop. During the practical part of the workshop, the participants will experience a simulation of a project, working in teams to develop a plan for a specific PBL approach. At the end of the workshop, the participants will present a visual and simplified plan for their proposal in a gallery walk. After a short presentation of one specific example, at the end of the workshop, the participants would have clarified some of the main elements of PBL, leaving a seed that can be deepened. The activities were planned inductively, and carried out in teams, with three main parts: basic concepts (1); planning a PBL approach (2); examples and discussion (3).

**Keywords:** Active Learning; Engineering Education; Project-Based Learning.

# 1 Introduction

Active learning puts the student at the centre of meaningful teaching-learning processes, in which students should understand why they are developing the expected competences. Environments with high levels of *engagement* and motivation will shape these processes. Active learning also implies moments of students' reflection about what they are learning, how, what for and with whom (Bonwell & Eison, 1991; Prince et al., 2020; Prince & Felder, 2006). Some studies show that Active Learning works. For instance, Freeman et al. (2014) point out that active learning is effective for students' assessment performance and Theobald et al. (2020) found a significant effect on the reduction of the gap in the performance of underrepresented students. Thus, teacher training for active learning (Neves et al., 2021) may be conducted to improve students' performance and inclusion (Lima et al., 2024).

A significant number of Active Learning Approaches may be implemented and can be classified along a continuum of students' degree of autonomy (Lima et al., 2024). Some approaches demand less autonomy from students like Think-Pair-Share; others demand a higher level of autonomy, such as Project-Based Learning (PBL).

The Problem and Project-Based Learning are the most widely used active learning approaches in engineering courses (Edström & Kolmos, 2014; Lima et al., 2024). PBL may assume different typologies according to the needs, context and learning outcomes (Helle et al., 2006), namely the exercise of project, project course, interdisciplinary project and curriculum project.

This workshop aims to support participants in planning an interdisciplinary Project-Based Learning (PBL) approach, exploring different dimensions of PBL, for instance, the problem, topic or theme to be addressed by the project

This workshop was developed under the activities of an Erasmus+ project aiming at creating a PBL framework for Digital Collaborative Teacher Training (https://pbl4tea.idea.uminho.pt/), which was piloted in two international teacher training settings.

# 2 Activities

In this workshop the participants will experience, as learners, how to work in a PBL environment. At the end of the workshop participants will develop an introductory proposal of a PBL approach, based on the research evidence, principles and dimensions of Project Based Learning (PBL). Thus, the workshop is designed to be interactive, engaging and collaborative.

The main objective of the workshop will be to initiate teachers to the PBL process and leave a seed that can grow in their institutions. For this reason, we plan the activities inductively, and we will carry out an action with a high intensity of active and autonomous work with the following ingredients: discussion of basic PBL concepts; development of a PBL proposal based on a sustainability theme; cooperative work among teachers; shared discussion on possible points for improvement of the proposal.

This workshop will require teamwork of 5 to 8 participants, preferably developed in workspaces with tables suitable for working together on flip-chart sheets. The necessary material will be a video projector, flip chart sheets, post-its and markers of various colours for each team. In the final part of the workshop, it will be necessary to hang on the walls the proposals developed on flip-chart sheets, for the development of a presentation in a gallery walk format.

It is intended that the teachers involved develop competences for the design and basic planning of learning processes based on interdisciplinary projects. The workshop will focus on activities carried out by the participants themselves that aim to build and present a PBL learning project proposal according to the work developed, in which the participants, in groups, analyse, discuss and reflect on a collaborative process as a way to start and plan a project.

The workshop will be based on the following activities briefly described above:

- PBL principles (15 minutes)
- PBL planning with 4 milestones:
    - Requirements for PBL planning (5 minutes)
    - Definition of the problem or theme for the PBL being planned (10 minutes)
    - PBL planning on flipchart sheets (20 minutes)
    - PBL proposal presentation on a gallery walk (20 minutes)
- Presentation of PBL cases and discussion of next steps (20 minutes).

As the initial 15 minutes may be too short to discuss the principles of PBL, we intend to reinforce the main concepts and misconceptions during the discussion phase. In addition, during the definition of the topic, which may be a phase with lengthy discussions, a set of guidelines will be presented to make the activity more directive and less prone to delays.

# 3 Expected Results

At the end of the workshop, the participants will gain a broad understanding of PBL principles and different ways of implementation. Moreover, they will develop a plan for delivering an interdisciplinary PBL approach that may be an inspiration for the next semester.

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# Workshop: What does it mean to teach teamwork?

Carola Hernández Hernandez[1], Nicolás Sánchez-Díaz[2], Carola Gómez[3]

[1] Profesora Asociada, Unidad de Apoyo a la Docencia, Decanatura, Facultad de Ingeniería, Universidad de los Andes.
[2] Asistente Graduado de Investigación, Unidad de Apoyo a la Docencia, Decanatura, Facultad de Ingeniería, Universidad de los Andes.
[3] Profesora Asistente, Facultad de Educación, Universidad Antonio Nariño.

Email: c-hernan@uniandes.edu.co, sanchezd2@uniandes.edu.co, cagomez14@uan.edu.co

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**Abstract**

Increasingly, transversal competencies take on a more relevant role in engineering education. Working in interdisciplinary teams is one of the great realities of how engineering is developed, and having the skills to do so has become one of the main demands of universities. For this reason, project-oriented courses are increasingly seen in curricular reforms in which students are organized into teams to have an experience closer to their professional performance. However, working in a team is often very difficult, not only for the students but also for the teachers who accompany the teams. In many cases, a strong orientation toward teams achieving the expected products because of the project generates terrible experiences for students who need to develop the skills, attitudes, and knowledge to be part of truly effective teams. Therefore, the purpose of this workshop is to show teachers what implications teaching students to work as a team has for their pedagogical practice, as well as to help them reflect on what type of knowledge they should generate in students so that they can promote the development of these skills. Using experiential learning, participants will form teams of 4 or 5 people in which they will develop a small challenge. This experience will allow the generation of reflective processes that lead participants to recognize the importance of effectively guiding teams and providing students with tools to promote the development of Teamwork competence, emphasizing the skills required. This way, it will be possible to conclude what it means to teach teamwork.

**Keywords:** Teamwork; Collaborative learning; active learning; socio-emotional skills.

## 1 Introduction

Teamwork has sparked great interest among employers as an essential skill for solving highly complex problems and coping with the challenges that the 21st century brings to each sector of our society. The benefits of teamwork encompass a wide range of characteristics that allow any institution to advance quickly and effectively in its objectives. For example, working in teams allows for the creation of new and disruptive ideas in the form of co-creation, including different perspectives, experiences, and diversity that contribute to creativity and innovation in the workplace (Tucker & Abbasi, 2012). In general, all productive sectors are highly interested in teamwork to promote workplace synergy, leading to better interaction, development, and achievement of results.

The demand for educating individuals who are increasingly competent in participating in high-performance teams has also generated pressure on educational systems. However, a large number of teachers have the erroneous belief that exposing students to different peer work activities can implicitly develop teamwork. Nevertheless, research in the field has shown that the absence of explicit theorization about teamwork and its characteristics can inevitably lead to an impoverished understanding of the subject, with subsequent unfavorable performance of the competence (Pinard et al., 2017; Therrien et al., 2017). This is in line with the approaches of Marin-Garcia and Lloret (2008), who describe in their study how higher education students consider these types of activities as overwhelming and extremely difficult to manage in the allotted times, even more so when teachers expect good quality in the products developed by the teams.

In light of this scenario, the question arises: What does it mean to teach teamwork? This hands-on workshop emerges from nearly a decade of reflecting on and testing activities in Project-Oriented courses to teach students how to work in teams (Hernández & Gómez, 2020). These courses, part of the university's basic training cycle (CBU), are offered to all undergraduate students. However, since they originate from the faculty of engineering, about 60% of the students come from various engineering disciplines. Starting from experiential learning and Kolb's cycle, different pedagogical strategies have been identified and put into play in this workshop space.

## 2 Activities

Teachers will undergo an experience similar to what their students might encounter in a project. The workshop is a simulation of a Kolb cycle (Sharlanova, 2004) concerning teaching teamwork.

In the first moment of the experience's development, we will use the marshmallow challenge. For this, we will work in groups randomly formed among the participants. We will use a marshmallow, a meter of wool, a meter of tape, and twenty spaghetti. The groups will try to build the highest self-sustaining structure with the marshmallow at the top in a maximum of 18 minutes.

In the second moment, they will reflect on their experience with the challenge, the lessons they learned from working in a team, and the needs this generated.

The differences between Teamwork and Group Work are introduced. After this, the skills that come into play when working as a team will be identified, emphasizing those that are oriented towards emotional management and not just oriented to the task or the products. With these elements, the critical elements of Teamwork are recognized.

From this, we reflect on the teacher's role in developing Teamwork competence using the experience lived in the marshmallow challenge and the conceptual components discussed in the third moment of the session.

Finally, with the experience, the theoretical approach, and the reflective discussion, some strategies are proposed to favor the "teaching" Teamwork competence process.

## 3 Expected results

Three main results are expected: first, participants will experience teamwork through a simple challenge; second, they will reflect on their experience through a guided, collaborative, and negotiated conversation with facilitators and classmates; and third, they will be able to identify the emotional and relational implications of teamwork, besides disciplinary demands of the task. Hence, participants should reflect on their role as teamwork teachers so that they can grasp the elements of emotional management within teams and thus think about strategies for teaching their students to work in teams.

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# Workshop: Learning that Makes a Difference – Cross-Disciplinary Student Projects With a Real Impact

Jens Myrup Pedersen[1], Natascha van Hattum-Janssen[2], Mateus Halbe Torres[1], Anabela Carvalho Alves[3], Diana Mesquita[4], Dianne Viana[5], Simone Borges Simão Monteiro[5].

[1] Cyber Security Group, Department of Electronic Systems, Aalborg University, Denmark
[2] Saxion Research & Graduate School, Saxion University of Applied Sciences, Enschede, the Netherlands
[3] ALGORITMI Centre, Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal
[4] Universidade Católica Portuguesa, Portugal
[5] University of Brasilia, Brazil

Email: jens@es.aau.dk, n.vanhattum@saxion.nl, mhto@es.aau.dk, anabela@dps.uminho.pt, dmesquita@ucp.pt, dianne.magav@gmail.com, simone_simao@yahoo.com.br

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**Abstract**

Working on real-world cases increases the motivation for learning, and prepares engineering students to become problem solvers. This is even more so for projects that have the potential to create visible and lasting impact, e.g. related to problems of social or environmental sustainability. Such problems are usually open ended, and require students to work together across - which can also create stress and uncertainty, because the road to success is not known from the beginning. This presents an excellent fit with the conference theme: "Overcoming Uncertainty – Building Bridges Between Society And Learning In The Future". The workshop is centered around three main challenges that we have experienced during the Erasmus+ EGALITARIAN project, which is focused on having students solving problems together across borders and disciplines: 1) How to scope projects, so they fit learning objectives and at the same time supports a real case. Student projects and courses are often defined through learning objectives. When working with real-world challenges, this can be challenging, since the real cases are not "designed" around the learning objectives. 2) How to ensure projects are making real impact. Working with NGOs and other organisations, can be rewarding. However, such organisations often have limited time and resources available, so it is important that the solutions developed are useful and create value. On the other hand, student projects are not always reaching that level of maturity, because the learning is in focus rather than the result. 3) How to support the students throughout the journey? Working with multiple stakeholders can be challenging. The format of the workshop is highly interactive, and consists of: Short introduction, Group work, where each group should come up with 1-3 ways to address each challenge and add it on a digital board, Presentations from the groups in plenum.

**Keywords:** Ethics and sustainability in engineering education, Experiences on Active Learning and PBL in engineering education, Innovative experiences in engineering education.

# 1 Introduction

Problem Based Learning (PBL) comes with many advantages when it comes to engineering education. It is highly motivating for the students, and at the same time it facilitates the learning of other competences than the purely technical, including problem solving skills, teamwork and collaboration skills and project management skills (Kolmos et al., 2004). In the recent years, the authors have been working on expanding the traditional PBL model to include international collaboration through Erasmus+ projects such as EPIC (Pedersen et al., 2019) and COLIBRI (Pedersen et al., 2016). Other projects have focused more on sustainability, often in collaboration with local communities and/or NGOs to not only create a good learning experience for the students, but also to achieve real impact, e.g. (Pedersen et al., 2020). These efforts of international/global collaboration and sustainability are all integrated in the Erasmus+ EGALITARIAN project (EGALITARIAN, 2024), where students from Denmark, Portugal, the Netherlands and Brazil work together across countries, cultures and disciplines in order to solve sustainability challenges in Brazil, with a particular focus on improving the life of waste pickers, who had their life impacted by the closing of the second largest dumpsite in the world, as described by Campos (2018).

There is no doubt that it is very rewarding for students to work on real problems with real partners, where their solutions can make a difference for real people, and at the same time the students acquire important problem-solving skills that will help them also in their future engineer careers. Moreover, their efforts can be used to create a more sustainable world, instead of "just" some assignment ending up on a shelf.

On the other hand, there are many challenges when interacting with the real world in this way: When communities and NGOs with already limited resources invest their already limited time and efforts in a project, they also need to see tangible results for the collaboration to be sustainable for them. This can create a dilemma from the university point of view, on how to balance the importance of the learning outcomes for the students with the importance of delivering a tangible outcome of the projects: For example, a supervisor might be less willing to see the students experimenting with a (not so promising) solution, from which they could learn a lot, take more control of the project, and lead them to a process that leads to a more ideal solution. Similar situations can arise regarding the learning objectives, and how they are balanced. Finally, supporting the students in operating in such complex environments also requires more from the supervisors – especially when it comes to the softer skills, which are already a challenging part of the supervision for many university faculty members. Given the high value of this kind of projects, it is important that the challenges are addressed, and this is exactly what this workshop searches to do: We hope to inspire other faculty members to take up this kind of highly rewarding projects, and we hope that together we can help finding solutions on some of the challenges that inevitable arises.

## 2 Activities

The first 15 minutes of the workshop will be spent on a short introduction to the EGALITARIAN project, highlighting main experiences, positive findings, and challenges. After this, the workshop participants are split in groups of four to spend 20 minutes on each of the questions:

1) How to scope projects, so they fit learning objectives and at the same time supports a real case? Student projects and courses are often defined through learning objectives. When working with real-world challenges, this can be challenging, since the real cases are not "designed" around the learning objectives, and it is often not clear before well into the project exactly what methods and tools are best suited to solve a particular problem. This point both relates to how learning objectives are defined (including the need for including cross-cultural aspects and communication), and to how projects are scoped (in particular keeping in mind that the approach should ideally be scalable and not rely too much on hand-held solutions).

2) How to ensure projects are making real impact? Working with NGOs and other organisations can be rewarding. However, such organisations often have limited time and resources available, so it is important that the solutions developed are useful and create value, so it becomes a positive investment for the collaboration partners, and not an activity that drain them from already limited resources. On the other hand, student projects are not always reaching that level of maturity, because the learning is in focus rather than the result.

3) How to support the students throughout the journey? Working with multiple stakeholders can be challenging: The level of support and feedback may vary depending on other priorities, and sometimes strategies and scopes change, especially during long-term collaborations, which might lead to a desire to change the scope or even to a loss of interest in the project. This comes on top of some of the other challenges with supervision (i.e. handling collaboration challenges), and on top of a role that for some supervisors is already quite different than traditional lecturing tasks.

For every task, each group will have to come up with 1-3 ways to address each challenge and add it on a digital board. To focus on the group work – and thus the interactive part of the workshop – there are no joint presentations in-between these three phases.

For each of the groups, the participants are encouraged to consider also their own local and regional contexts. PAEE/ALE traditionally has a strong global representation, and since the challenges are often different in different cultures and regions, this will add a high value to both the discussions and the resulting conclusions/contributions.

At the end, the last 15 minutes is allocated for the groups to go over their suggestions.

# 3 Expected results

The expected results of the workshop are three-fold:

1. The participants will get inspiration and concrete didactical tools to work with real-world problems, in collaboration with the surrounding society and organisations including companies, communities and NGOs.
2. The participants will share experiences from supervision of student projects. Even reflections from different settings of supervision, and different ways of collaboration, are valuable.
3. The participants will contribute to solving some of the main challenges in this way of working with student projects through concrete ideas and suggestions. These can potentially be used in the Erasmus+ EGALITARIAN project, and thus the experiences will be later reported to a wider audience.

All tangible outcomes of the workshop will be shared with the participants afterwards. It will also be made available through the website of the EGALITARIAN project.

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