Maturity Model based on Multiple Levels of Learning: Proposal for Application in an Institution of Engineering Education, with a focus on Sustainable Project Based Learning

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Abstract

One of the fundamental properties that an Institution of Engineering Education (IEE) must have is the ability to learn, from which emerges the concepts of (i) organizational learning and learning organization, (ii) organizational teaching and teaching organization, and (iii) organizational learning-teaching and learning-teaching organization. Whereas an IEE must teach future engineers how to act and to teach in organizations that learn and teach, the very IEE should be treated as an organization that, besides teaching, also mandatorily must learn in order to evolve in how to teach. The matrix of summary of questions about the performance of an IEE, developed from the concept of multiple levels of learning, consolidates the general framework for the verification of an IEE maturity model, in terms of four "Es" of Excellence: efficiency, efficacy, effectiveness, and evidence. With regard to future engineers, they must learn how to act and teach in organizations that learn and teach. On the other hand, teachers should not only teach students on how to act and teach, but also changing the very process of teaching. With a focus on Sustainable Project Based Learning and based on the contents of the above mentioned matrix positions, it is presented the first set of specific questions regarding competences of both, students and teachers of an IEE in order to be assigned a maturity level to that IEE.

Keywords: Engineering Education, Project-Based Learning, Multiple Levels of Learning, Maturity Model.

1 Introduction

The approach focuses on competences - knowledge, skills and attitudes - to be developed by both, students and teachers of Institutions of Engineering Education (IEE). Regarding students, they must learn to act and teach in organizations that learn and teach. Teachers, on the other hand, should not only teach students to act and teach in organizations that learn and teach, but also changing the very process of teaching.

In the context of learning and teaching, the framework takes as its cornerstone a David Wasdell's phrase, present in the first and last paragraphs of Wasdell (1993):

> "If a company is to flourish in a changing world, its rate of learning must exceed the rate of change in its environment."

According to Argyris and Schön (1996), an organization learns when it acquires information of any kind by any means, characterizing three components in a generic scheme for organizational learning and teaching: (i) information content, which is the product to be learned; (ii) the learning process, which consists in acquiring, processing and storing information, and (iii) the students to whom the process is assigned. In this paper, learning refers to both, the results obtained and the learning process that yielded these results. According to Fiol and Lyles (1985), organizational learning concerns the development of new knowledge or insights that have the potential to influence behavior. A learning organization is one that facilitates the learning of all its members and continuously transforms itself (Pedlar et al., 1991).

Regarding the relationship between learning and teaching, the important point to note is the attention to teaching, as a necessary counterpart to learning (French and Bazalgette, 1996). From this argumentation, emerge the concepts of both, organization that teaches and the organization that teaches and learns, which are key components of the approach. The approach essentially combines the concepts of single, double and triple learning with those of multiple levels of feedback (Wasdell, 1993), resulting in the Matrix of Summary Questions on the performance of an IEE that teaches and learns.

2 Systems Thinking

The approach developed by Wasdell (1993) for systems (Human Activities) with Multiple Levels of Learning has the systems thinking as one of its pillars. In terms of systems models, Checkland (1981) considers systems within the limits of human knowledge and systems that go beyond such a knowledge. In the space of human knowledge, there are two major classes: (i) natural systems, which deal with the origin of the universe and the processes of natural evolution in which the human being is considered only as a living being of the biological sphere; and (ii) systems arising from the explicit action of the human being. As members of this latter class, systems of human activities (SHA) surface when human consciousness itself becomes an explicit part of the systems origin.

Focusing on system purpose, Guarajedagui and Ackoff (1996) characterize four types of systems, in terms of the system (whole) and its parts having or not having purpose: (i) Deterministic ➔ both, the whole and the parts have no purpose, (ii) Animated ➔ the whole has purpose and its parts have not; Social ➔ both, the whole and the parts have purpose, and (iv) Ecological ➔ the whole has no purpose and the parts have. In terms of these concepts, the social system is the one applicable to SHA. As open systems, SHA consume inputs available in society and make it possible that society consumes the outputs produced by them. The basic premise is that the formation of value or simply Valuation, regarded as the ultimate purpose of any SHA, encompasses both the generation of value and the appropriation of this value to stakeholders, which are individuals or social groups, internal and external to the SHA which may affect or be affected by the SHA Valuation. It is noteworthy that this process of values appropriation by different stakeholders addresses facing the issue of intragenerational and intergenerational distribution and access, involving justice between present and future generations, placing centrally the issue of sustainability in the generation and dissemination of values.

3 Sustainability and Environmental Responsibility

Among the fundamental values in human action, Sustainability is increasingly present, understood as the ability of purposeful systems to maintain its stability and responding to endogenous or exogenous impacts, thus ensuring its permanence and reproducibility, even under new conformations. This vision of Sustainability is linked to the concept of resilience (Holling 2001, Folke et al., 2004). At the level of society as a whole, Sustainability thus consists on value of larger scale and higher level of aggregation, to be achieved systemically. At the organizational level, sustainability is presented as a set of values and guiding principles to be permanently learned and structuring the organization, and the effective actions for achieving these is known as social and environmental responsibility. The social and environmental responsibility incorporates the essential attribute of sustainability to SHA with Multiple Levels of Learning treated by Wasdell (1993). According to Rosnay (1979), the terrestrial ecosystems, whose basic elements are matter, energy and information, can be structured in terms of atmosphere, hydrosphere, lithosphere and biosphere for: (a) operationalize the cycles of production, storage, consumption and regeneration of living matter; (b) Make use of the flow and irreversible inexhaustible solar energy; and (c) Regulate the functioning of the ecosystem as a whole.

The SHA depends on functioning ecosystems to which they belong. In the short term, or even better, in real time, the physical existence of SHA should be understood as part of the physical world in which they are included, getting low entropy material and energy resources inputs, using these inputs as throughputs crossing the system and giving it back to the environment in the form of high entropy material and energy resources. Thus, human activities should be developed in a manner that does not interfere with the natural cycles they are based on, thus not violating the planet resilience and, at the same time, not depleting natural capital to be transmitted to future generations. Besides the physical aspect, the ethical principle of equity should be considered, in the sense that each individual (including future generations) is entitled to the same environmental space - amount of energy, water, land and non-renewable raw materials - which should be used sustainably.

The World Commission on Environment and Development report Our Common Future (http://www.un-documents.net/wced-ocf.htm) is a landmark in defining and establishing the principles of sustainable development. According to the report, sustainable development is development that meets present needs without compromising the ability of future generations to meet their own needs.

While SHA are systems in which both the whole and its parts are purposeful, however they occur, from the biophysical point of view, as a subsystem within an ecological system, where the parts are purposeful but the whole has no purpose. The SHA thus becomes a driver highly determinant of the ecological system, which can be put at risk in part or in whole, but fundamentally endangering the very SHA. Thus, as the SHA are purposeful, their purposes must be set in order to self-regulate their actions in the context of the ecological system to which they belong. Thus, SHA should not be driven only by the strict and immediate specific interests, but also be self-regulated in their purposes, so that

their participation results in sustainable systemic cohesion. Thus, organizations should have systematically among its purposes: (i) the best selection in the use of resources, economic, social or natural, so that such selection promotes the least damage to ecological system cohesions and therefore that the least affects synchronic solidarity (intra-generational) and diachronic (intergenerational). For this purpose, it is necessary as clearly as possible the material and energy balances associated with the use of such resources; (ii) the best choice and search of efficient and ecoefficient technologies and techniques to be developed; (iii) The best choice of processes and products with least impact in terms of waste and byproducts, and one should have clear understanding systemic analysis of the set of their life cycle; (iv) the acknowledgment of responsibility by the organization for the positive and negative externalities produced along the company, and provide for the recovery and valuation of such benefits or costs, and shall respectively bear with them or be rewarded; (v) Take the necessary clarity and responsibility from the effects of the actions of the organization in relation to the social and economic order, both positive and negative, both spatial and temporal, both material and cultural, and be responsible for such effects and therefore having them as part of its strategic objectives. The concept of Sustainability leads to Sustainable Valuation. The basic premise that society must be part of sustainable ecosystems gives rise to the idea of "Sustainable Systems of Human Activities - SSHA". Thus, with the introduction of the principle of sustainability, the pursuit of achieving goals by organizations takes shape becomes quite distinct from conventional.

4 System Multiple Levels of Learning

The System of Multiple Levels of Learning developed by Wasdell (1993), considers an SSHA as a purposeful open system. The SSHA Level Zero regarding learning corresponds to a system without feedback loop. At this level, despite changes in the environment, an SSHA has no way to adapt, no change in the behavior and performance of the system.

Climbing to Level 1, the system incorporates the Learning Cycle 1, with the possibility of adapting the behavior depending on the feedback received on the results. This SSHA progress, called Evolution 0/1, ranges from mere adjustments until the full transition to a new system behavior. Figure 1 shows graphically the evolution 0/1.

Now rising to Level 2 of the SSHA, Cycle 2 of learning is incorporated, in which the possibility of changes in the behavior of SSHA occurs due to the feedback received not only on the results obtained by Cycle One of the learning system, but also on the results of Cycle One itself. This SSHA progress, called Evolution 1/2, which has the Evolution 0/1 immersed in it, ranges from mere adjustments to the transition to a new system behavior, now also in terms of learning. Continuing in this embodiment of learning cycles, the SSHA progress from Level n-1 to Level n, called Evolution (n-1)/n, which has the set {Evolution 0/1, Evolution 1/2, Evolution2/3, ..., Evolution (n-2)/(n-1)} immersed therein, includes from mere adjustments to complete the transition to a new behavior of the system in terms of learning. According to Wasdell (1993), as this merger can theoretically continue indefinitely, there is no limit to the SSHA in learning. Within this work, given the importance of the unique features of the first four cycles of learning, this set of cycles gets a special attention.

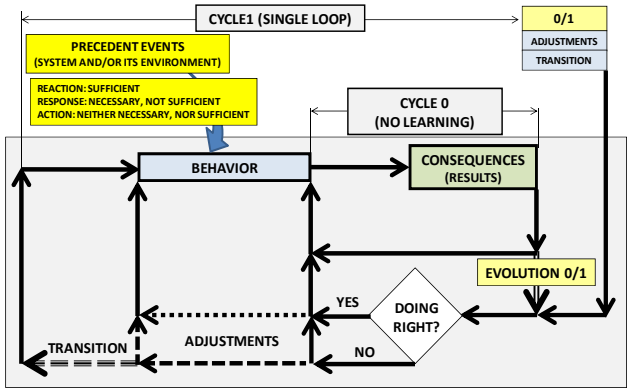

Figure 1 - Evolution 0/1

When dealing with organizational learning, Garavan (1997) considers the adaptive and regenerative types defined by Argyris (1987). The adaptive or single-loop learning, in which the behavior must obey assumptions of organizational learning, without questioning values of the theory of action, usually occurs sequentially, incrementally and focused on issues and opportunities within the traditional organizational activities. The regenerative cycle or double-loop occurs when the organization starts to question values of the theory of action, strategies and assumptions to which the behavior is submitted. The concept of triple-loop (Cycle 3) discussed in Rome and Wittloostuijn (1999) refers to the

question from the perspective of the context to which the assumptions must have adherence. The continued expansion of this movement gives rise to the quadruple-loop (Quadruple Cycle), questioning the referential on which the behavior, assumptions and contexts are based. The logical sequence corresponding to the first four cycles is then Referential➔ Contexts➔ Assumptions➔ Behavior➔ Results. As shown in Figure 2, these four cycles can be linked to four indicators of excellence: (i) Efficiency ("Doing Right") ➔ Simple Cycle; (ii) Efficacy ("Do the Right Thing") ➔ Double Cycle; (iii) Effectiveness ("Doing Right the Right Thing") ➔ Triple cycle; and (iv) Evidence ("Right Referential for Doing Right the Right Thing ") ➔ Quadruple Cycle.

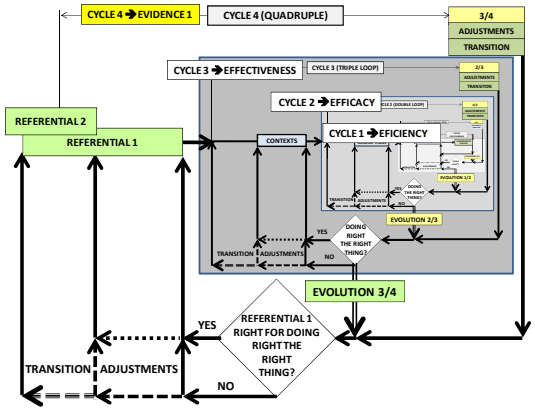

Figure 2 - Association of Learning Levels with Excellence

Figure 2 provides the framework to general questions relating excellence indicators of, with increasing immersion:

1. Behavior has results aligned with assumptions? (➔ Efficiency).
2. Assumptions associated to contexts are valid (➔ Efficacy) 2.1. for Doing Right? (➔ Efficiency).
3. Contexts arising from Referential 1 are adequate (➔ Effectiveness) 3.1. for Doing the Right Thing? (➔ Efficacy); and 3.2. for Doing Right? (➔ Efficiency).
4. Referential 1 is in state of the art (➔ Evidence) 4.1. for Doing Right the Right Thing? (➔ Effectiveness); 4.2. for Doing the Right Thing? (➔ Efficacy); and 4.3. for Doing right? (➔ Efficiency).

5 Questions about the Indicators of Excellence

Considering an Institution of Engineering Education (IEE) as a Learning/Teaching Organization, these concepts give rise to a Matrix of Summary Questions, shown in Figure 3.

QUESTIONS ON IEE SUSTAINABILITY PERFORMANCE				RESULTS IN MULTIPLE LEARNING CYCLES							
				BEHAVIOR		ASSUMPTIONS		CONTEXTS		REFERENTIAL	
				COMPETENCES		COMPETENCES		COMPETENCES		COMPETENCES	
				1 - ACT	2 - TEACH	3 - ACT	4 - TEACH	5 - ACT	6 - TEACH	7 - ACT	8 - TEACH
PROCESSES	A - LEARNING	1 - ARE STUDENTS LEARNING TO	2 - ARE TEACHERS EVOLVING IN TEACHING STUDENTS TO	ACT IN SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?	TEACH IN SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?	ACT IN ASSUMPTIONS OF SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?	TEACH ASSUMPTIONS OF SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?	ACT IN CONTEXTS OF SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?	TEACH CONTEXTS OF SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?	ACT IN REFERENTIAL OF SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?	TEACH REFERENTIAL OF SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?
				DOING RIGHT		DOING THE RIGHT THING		DOING RIGHT THE RIGHT THING		RIGHT REFERENTIAL FOR DOING RIGHT THE RIGHT THING	
				E1: EFFICIENCY		E2: EFFICACY		E3: EFFECTIVENESS		E4: EVIDENCE	
	B - TEACHING	3 - ARE TEACHERS TEACHING STUDENTS TO		ACT IN SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?	TEACH IN SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?	ACT IN ASSUMPTIONS OF SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?	TEACH ASSUMPTIONS OF SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?	ACT IN CONTEXTS OF SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?	TEACH CONTEXTS OF SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?	ACT IN REFERENTIAL OF SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?	TEACH REFERENTIAL OF SUSTAINABLE ORGANIZATIONS THAT LEARN AND TEACH?

Figure 3 - Matrix of Summary Questions on IEE Sustainability Performance

Figure 3, which following questions regarding the "4 Es" of Excellence:

E1 ➔ EFFICIENCY: BEHAVIOR

A - Learning

1. **Focus**: Efficiency of IEE students in learning ➔ **Are IEE students learning to**

1.1. Act in sustainable organizations that learn and teach?

- Can IEE students identify, characterize and propose the operationalization regarding:
  Block E1: Questions regarding Efficiency.
  (i) the eco-efficiency of the provision of funds to be obtained by the organization? (ii) the technical and eco-efficient technologies in using and processing resources? (iii) the products of greater value between the various sustainable products resulting?

1.2. Teach in sustainable organizations that learn and teach?

- Are students able to master and use resources and strategies to promote instructional approaches regarding: **Block E1: Questions regarding Efficiency.**

2. **Focus**: Efficiency of IEE teachers in learning ➔ **Are IEE teachers evolving to teach IEE students to**

2.1. Act in sustainable organizations that learn and teach?

- Are IEE teachers able to keep up and innovate regarding: **Block E1: Questions regarding Efficiency.**

2.2. Teach in sustainable organizations that learn and teach?

- Are IEE teachers able to keep up and innovate in the field and use of instructional approaches regarding: **Block E1: Questions regarding Efficiency.**

B - Teaching

3. **Focus**: Efficiency of IEE teachers in teaching ➔ **Are IEE teachers teaching students to**

3.1. Act in sustainable organizations that learn and teach?

- Are IEE teachers able to master and use resources and strategies for instructional approaches that lead to the identification, characterization and operation of: **Block E1: Questions regarding Efficiency.**

3.2. Teach in sustainable organizations that learn and teach?

- Are IEE teachers able to master and use resources and strategies for instructional approaches that lead to the teaching of the identification, characterization and operation of: **Block E1: Questions regarding Efficiency.**

E2 ➔ EFFICACY: ASSUMPTIONS

A – Learning

1. **Focus**: Efficacy of IEE students in learning ➔ **Are IEE students learning to**

1.3. Act on assumptions of sustainable organizations that learn and teach?

- Can IEE students identify, characterize and propose the operationalization regarding:
  Block E2: Questions regarding Efficacy
  (i) the environmental elements present in defining organization strategies? (ii) the achievement of goals of the core activities of the organization? (iii) the environmental impacts related to the core activities of the organization? (iv) the environmental impacts related to the support activities the organization? (v) the proposal of measures and programs for mitigating negative environmental impacts and promote positive impacts? (vi) the proposal of reviewing and redesigning management strategies of the organization .

1.4. Teach assumptions in sustainable organizations that learn and teach?

- Are IEE students able to master and use resources and strategies to promote instructional approaches regarding: **Block E2: Questions regarding Efficacy.**

2. **Focus**: Efficacy of IEE teachers in learning ➔ **Are teachers evolving to teach IEE students to**

2.3. Act on assumptions of sustainable organizations that learn and teach?

- Are IEE teachers able to keep up and innovate regarding: **Block E2: Questions regarding Efficacy.**

2.4. Teach assumptions in sustainable organizations that learn and teach?

- Are IEE teachers able to keep up and innovate in the field and use of instructional approaches regarding: **Block E2: Questions regarding Efficacy.**

B - Teaching

3. **Focus**: Efficacy of IEE teachers in teaching ➔ **Are IEE teachers teaching IEE students to**

3.3. Act on assumptions of sustainable organizations that learn and teach?

- Are IEE teachers able to master and use resources and strategies for instructional approaches that lead to identification, characterization and operation regarding: **Block E2: Questions regarding Efficacy.**

3.4. Teach assumptions of sustainable organizations that learn and teach?

- Are IEE teachers able to master and use resources and strategies for instructional approaches that lead to the teaching of identification, characterization and operation regarding: **Block E2: Questions regarding Efficacy.**

E3 ➔ EFFECTIVENESS: CONTEXTS

A – Learning

1. **Focus**: Effectiveness of IEE students in learning ➔ **Are IEE students learning to**

1.5. Act in contexts of sustainable organizations that learn and teach?

- Can IEE students identify, characterize and propose the operationalization regarding:
  Block E3: Questions regarding Effectiveness.

(i) to qualify and quantify how the organization's activities are affected by socioeconomic and environmental context in which they occur, changing its impact on society? (ii) to qualify and quantify how the organization's activities affect the socioeconomic and environmental context in which they occur, changing its impact on society?

1.6. Teach contexts in sustainable organizations that learn and teach?

- Are they able to master and use resources and strategies to promote instructional approaches regarding: **Block E3: Questions regarding Effectiveness.**

2. **Focus**: Effectiveness of IEE teachers in learning ➔ **Are teachers evolving to teach IEE students to**

2.5. Act in contexts of sustainable organizations that learn and teach?

- Are teachers able to keep up and innovate regarding: **Block E3: Questions regarding Effectiveness.**

2.6. Teach contexts in sustainable organizations that learn and teach?

- Are teachers able to keep up and innovate in the field and use of instructional approaches regarding: **Block E3: Questions regarding Effectiveness.**

B - Teaching

3. **Focus**: Effectiveness of IEE teachers in teaching ➔ **Are IEE teachers teaching students to**

3.5. Act in contexts of sustainable organizations that learn and teach?

- Are teachers able to master and use resources and strategies for instructional approaches that lead to the identification, characterization and operation regarding: **Block E3: Questions regarding Effectiveness.**

3.6. Teach contexts in sustainable organizations that learn and teach?

- Are teachers able to master and use resources and strategies for instructional approaches that lead to teaching the identification, characterization and operation regarding: **Block E3: Questions regarding Effectiveness.**

E4 ➔ EVIDENCE: REFERENTIAL

A - Learning

1. **Focus**: Evidence of IEE student in learning ➔ **Are IEE students learning to**

1.7. Act in the referential of sustainable organizations that learn and teach?

- Can IEE students understand theoretically and methodologically:
  Block E4: Questions regarding Evidence.
  a) the worldview guiding the organizations as well as their self-image and business?
  b) reconstruct the worldview, self-image and business, based on solidarity and systemic principles of synchronic and diachronic sustainability?

1.8. Teach in referential of sustainable organizations that learn and teach?

- Are IEE students able to master and use resources and strategies to promote instructional approaches regarding: **Block E4: Questions regarding Evidence**

2. **Focus**: Evidence of IEE teachers in learning ➔ **Are IEE teachers evolving in teaching IEE students to**

2.7. Act in referential of sustainable organizations that learn and teach?

- Are IEE teachers able to keep up and innovate regarding: **Block E4: Questions regarding Evidence.**

2.8. Teach on referential of sustainable organizations that learn and teach?

- Are IEE teachers able to keep up and innovate in the field and use of instructional approaches regarding: **Block E4: Questions regarding Evidence.**

B - Teaching

3. **Focus**: Evidence of IEE teachers in teaching ➔ **Are IEE teachers teaching students to**

3.7. Act in the referential of sustainable organizations that learn and teach?

- Are IEE teachers able to master and use resources and strategies for instructional approaches that lead to the identification, characterization and operation regarding: **Block E4: Questions regarding Evidence.**

3.8. Teach in the referential of sustainable organizations that learn and teach?

- Are IEE teachers able to master and use resources and strategies for instructional approaches that lead to teaching the identification, characterization and operation regarding: **Block E4: Questions regarding Evidence.**

6 UnB and PUC/SP Engineering Programs as Pilots for Model Application

Both, the University of Brasília undergraduate program in Production Engineering and the Pontifical Catholic University of Sao Paulo undergraduate program in Biomedical Engineering will be the pilot for application of the proposed model of multiple levels of learning. It follows a brief description of the UnB program, where the model will be initially implemented.

The University of Brasilia's Production Engineering Undergraduate Program (PEUP/UnB) is an evening program, with a normal flow of twelve semesters, for a total of 3,600 hours of activities. Since the second semester of 2009, when the

program began, 50 new students are admitted each semester, which will result in a steady student body of about 600 students. Following a problem-based learning and focusing on project activity, the contents of Synthesis, Integration and Entrepreneurship (blocks S1 to S6) shown in Figure 4 comprise the backbone and conductive line of the program.

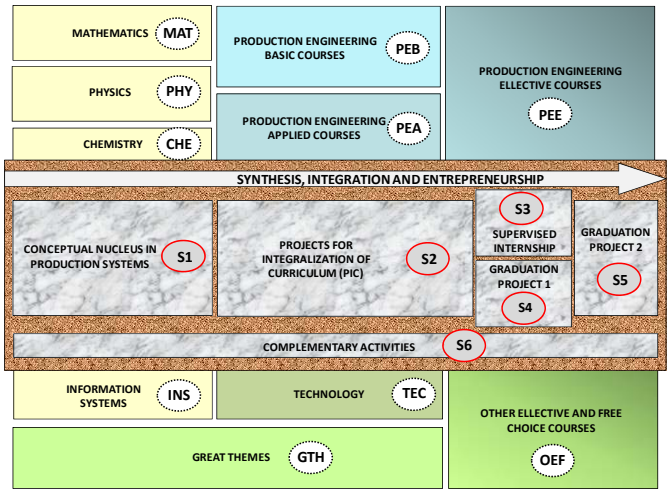

Figure 4 – PEUP/UnB Curriculum Blocks

The Core Concept in Production Systems (Block S1) covers basics of Production Engineering, value formation, ergonomics, human behavior, design methodology and sustainable development. Block S2 is focused on a set of projects to be developed in the context of sustainability. Starting at the fourth semester of the normal coursework, students develop seven Projects for the Integralization of Curriculum (PIC1 to PIC7), whose complexity grows each period, seeking to consolidate the methodological aspects with issues addressed in disciplines of technical contents, with the reality brought about by external agents linked to each design theme. The item Graduation Project (Blocks S4 and S5), aiming at facilitating (i) the scientific initiation, (ii) the acquisition of experience in literature, (iii) the writing of technical reports, (iv) the preparation and oral presentation, and (v) the ability to work both in a team as individual, encompasses two courses: Graduation Project 1 (Block S4) and Graduation Project 2 (Block S5). The Supervised Internship (S3) consists of field work to gain experience in a real Production Engineering environment. The Supervised Internship should preferably be developed in association with the Graduation Project 1 (Block S4), in order to align the Graduation Project with the Supervised Internship activities. The Complementary Activities (Block S6) encompasses student participation in undergraduate research projects, multidisciplinary projects, community projects, technical visits, participation in events, prototype development, participation in junior companies and entrepreneurial activities.

As shown in Figure 5, the PIC associated with the Block S2 of the curriculum have four anchors as its basic pillars: A Methodology (seven Production Systems Projects courses: PSP1 to PSP7); A2 – Technical contents (related to Production Engineering areas); A3 – Reality (real problems brought on by External Agents) and A4 – Possibilities of enrichment (other courses with specific interests in the problems being solved).

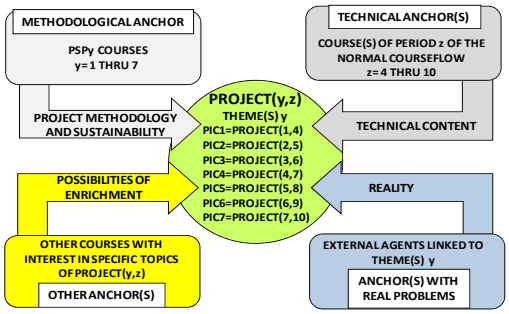

Figure 5 – Anchor Framework for PIC1 a PIC7

Every semester there will be about 350 students to be allocated to seven PIC. Based on the model of anchors A1 to A4, at the moment the PEUP/UnB is using the following settings for the seven PIC: **1. PIC1 ➔** A1: PSP1, A2: Probability and Statistics (PS), A3: Databases Providers; A4: To Be Defined. **2. PIC2 ➔** A1: PSP2, A2: Engineering Economics (EE), Information Systems in Production Engineering (ISPE); A3 and A4: TBD. **3. PIC3 ➔** A1: PSP3, A2: Operations Research in Engineering 1 (POE1); A3 and A4: TBD. **4. PIC4 ➔** A1: PSP4; A2: Production Planning and Control (PPC), Systems

Simulation (SS), Health and Safety at Work (HSW); A3 and A4: TBD. **5. PIC5** ➔ A1: PSP5; A2: Production Quality Management (PQM); A3 and A4: TBD. **6. PIC6** ➔ A1: PSP6; A2: Product Engineering (PE), Logistics and Supply Chain (LCS); A3 and A4: TBD. **7. PIC7** ➔ A1: PSP7; A2: Strategic Management (SM); A3 and A4: TBD.

According to Figure 6, the sequence of seven PEUP/UnB PIC defines a framework of increasing knowledge, for both students and teachers that allows the application of the model in a modular fashion. Efficiency, Efficacy, Effectiveness and Evidence measures shown in Figure 3 will result from the application of the model.

The effective implementation of sustainability principles contained in the four "Es" of excellence, in a gradient of complexity, will be accomplished through systemic performance questions associated with sustainability, methodologically applied by validation procedures specifically developed for each step of the sequence PIC1 to PIC7.

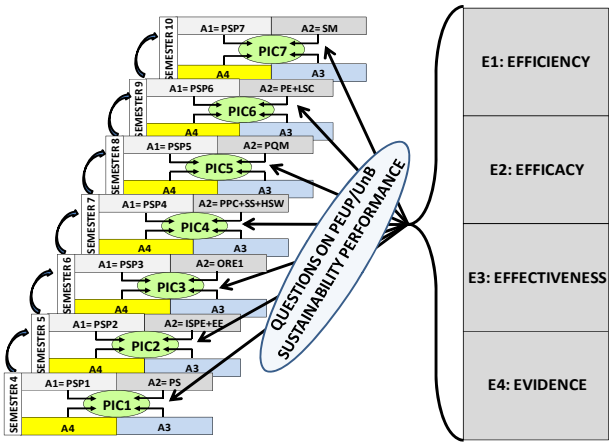

Figure 6 – Framework for the Application of the Model at PEUP/UnB

7 Conclusions

Both, the PEUP/UnB and the Pontifical Catholic University of Sao Paulo Biomedical Engineering Undergraduate Program will be the pilot for application of the proposed model of multiple levels of learning. Taking into account that one of the outstanding features of both programs is problem-based learning, via sustainable projects, it is expected to obtain a degree of maturity of high excellence for these programs and thereby to encourage other academic institutions interested in sustainability to include PBL as an instructional approach in their undergraduate programs.

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