The Project Based Learning Combined with Problem Solving Based Learning in Industrial Engineering Programs

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Abstract

Industrial Engineering Programs are changing in the world pushed by technological trends, competitive pressures and new theoretical paradigms like Smart Advance Manufacturing, Cyber-physical Factory Design and other Industry 4.0 approaches.
This work starts with a primary assumption: Learning approaches in engineering must to be applied in a different way before changing the contents of courses or the whole program.
This work define two primary pedagogical strategies to be aligned with needs and trends in the industry: the project based learning (PbL) and the problem solving based learning (PSbL); using a study case research method.
Conclusions can be separated on two analytical dimensions: 1-Significative Learning for life and 2-Technical Skills for Industrial Engineering Design. In the dimension number 1, PbL and PSbL must to be articulated between them and linked with real life situations. These should be essentially applied in a multi-disciplinary environment and with a strong follow up in order to get practical results. On the other hand, for technical skills reinforcement, PSbL must be mandatory and PbL a practical way in order to aim goals with pragmatism and tangible results orientation.
In both analytical dimensions, the use of industrial standards and technical training needs should drive the learning objetives.

Keywords
Project based learning, Problem Solving based Learning, Industrial Engineering Education, Industry 4.0

1. Introduction

Industrial Engineering is the science and profession that study goods and services production systems, specially the complex ones which require the optimal yield and integration of several resources such materials, money, equipment, economic resources, energy, people, infrastructure, information, technologies, etc.

As other scientific fields, Industrial Engineering is built on core and formal paradigms (Kuhn T., 1962) that are in constant change influenced by other emerging scientific fields such materials engineering, foods technologies, mechatronics, ITC technologies and data analytics, robotics, artificial intelligence and cognition, green energies, cyber-physical systems, etc. Several changes and trends related with this knowledge fields can be associated with some industrial competitiveness big changes in the whole world and what some thinkers call ñFourth Industrial Revolutionò or ñIndustry 4.0ò (Frerich S. et al, 2016).

This ñparadigmsò change introduce the need of re-thinking the concept and classical way of ñindustrial engineering educationò not only in the perspective of contents but in the teaching and learning approach, integrated with research and social and community actions (Frerich et al, 2016). That is why Industrial Engineering Programs are changing in the world pushed by all this technological trends, competitive pressures and new theoretical paradigms conceptualized in technical topics like Smart Advance Manufacturing, Cyber-physical Factory Design and other Industry 4.0 approaches.

This work focusses on two big education trends: Problem Solving based Learning and Project based Learning. In addition, it starts with a primary assumption: Learning approaches in engineering must to be applied in a different way before changing the contents of courses or the whole program. The epistemological approach is hermeneutical based on interpretativism using the study case research method.

This document is organized as follow. In the first section, a quick overview of literature review is presented. Then, a section with the study case is characterized and main facts are presented. Finally, data analysis and conclusions sections are develop.

1. Literature Review

1.1 Industrial Engineering Education Trends

Engineering Education is a knowledge relative new. According with UNESCO (2010), historically ñthe most crucial period in the development of engineering were the eighteenth and nineteenth centuries particularly the Iron and Steam Ages the second Kondratiev wave of innovation and successive industrial revolutionsò.

Modern Engineering Education began in Germany (because of the mining industry), Czech Republic (Czech Technical University in 1707) and France (*École Nationale des Ponts et Chaussées* founded in 1747, *École des Mines* in 1783 and *École Polytechnique*, in 1794). French model (developed with a hard military tradition) influenced the development of engineering education institutions around the world at the beginning of the nineteenth century. Alternative models like German, Rusian and the USA (for example, West Point in 1819), were developed in similar military foundations either.

Since the twentieth century to date, engineering grew thanks to professional societies, journals, meetings, conferences, and the professional accreditation of exams, qualifications and universities programs. In addition, international agreements relating to accreditation and the mutual recognition of engineering qualifications and professional competence have impulse the impact of engineering, such Washington Accord (1989), Sydney Accord (2001), Dublin Accord (2002), APEC Engineer (1999), Bologna Declaration (1999), Engineers Mobility Forum (2001) and the Engineering Technologist Mobility Forum (2003).

The 21th Century came with worldwide challenges. Engineering must to focus in two issues of truly global proportions: climate change and poverty reduction (UNESCO, 2010). This mean that new professionals and researchers should ñto engineering the world to avert an environmental crisis caused in part by earlier generations in terms of energy use, greenhouse gas emissions and their contribution to climate change, and engineering the large proportion of the worldôs increasing population out of poverty, and the associated problems encapsulated by the UN Millennium Development Goalsò (UNESCO, 2010).

This challenge implies some urgent changes in Engineering Education approaches. Some of the changes include:
1-Engineering Education should be aligned with global purposes and priorities.
2-Engineering Education should be rethought according with new technological paradigms and international employment needs.
3-Educational system must be restructured in terms of a systematic approach of ongoing improvement, a systematic approach of operational excellence in the whole institution rather than ñsome departmentsò and a systematic approach of program internationalization and research projects.
4-Pedagogical approaches in education are defined responding to formal Engineering Education Model that include: ñé

a) pathways and linkages for students to engage with the universityôs research activities, often building upon rigorous, applied teaching in the engineering fundamentals;
b) a wide range of technology-based extra-curricular activities and experiences available to students, many of which are student-led;

c) multiple opportunities for hands-on, experiential learning throughout the curriculum, often focusing on ñproblem identification as well as problem solution,ò and typically supported by state of the art maker spaces and team working areas;
d) the application of user-centered design throughout the curriculum, often linked to the development of studentsô entrepreneurial capabilities and/or engaged with the social responsibility agenda;
e) emerging capabilities in online learning and blended learning;
f) longstanding partnerships with industry that inform the engineering curriculum as well as the engineering research agenda.

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It is important to emphasize the roll of multi-cultural and international collaboration skill in the new profile of industrial engineers. In a globalization context is typical for new engineers to work in different multi-cultural contexts that implies specific competences in order to be successful. Figure 1 shows this needs and emergent new models of international education.

Figure 1.New Model of International Education of Engineers (UNESCO, 2010)

Industrial Engineering Education is relative complex due the diversity in the knowledge areas related to the field. There are different frameworks of the body of knowledge of the profession but universities trend to focus on long term skills like problem analysis and solving, lifelong learning, researching, statistical thinking and systemic thinking. Table 1 shows two popular body of knowledge of Industrial Engineering.

It is too much difficult to cover all the topics in a standardized way when a body of knowledge is defined but it is evident that we can see some lacks on this proposals. For example, on one hand, topics like Sustainability, Simulation and Automation are not visible in the IISE framework. On the other hand, Safety and Operations Engineering are not visible in the Lima M. R. et al (2012) study; in addition, Engineering Management is reduced to Project Management and Facilities Engineering is reduced to Maintenance.

Industry 4.0 (Fourth Industrial Revolution) is still a relative fuzzy concept but it is useful to describe the cyber-physical (CP) way to design and control systems, products, technologies and services. Without a doubt, Industry 4.0 or CP Systems and Products Revolution is a huge influence in Industrial Engineering profession and science, so, that means universities and technical institutions must to take it into account in their education models introducing both, new contents but pedagogical practices centered in virtual worlds applications, interoperability frameworks, interconnected systems design and control, Data Analytics Approaches and Smart Cyber-physical Systems.

Table 1. Typical Body of Knowledge of Industrial Engineering

Area of the Body of Knowledge (Institute of Industrial and Systems Engineers, IISE)	Area of the Body of Knowledge (Lima M. R., Mesquita D., Amorim M., Jonker G., Flores M.A., 2012)
1. Work Design & Measurement	Simulation
2. Operations Research & Analysis	Operations Research
3. Engineering Economic Analysis	Economics Engineering
4. Facilities Engineering & Energy Management	Maintenance
5. Quality & Reliability Engineering	Quality
6. Ergonomics & Human Factors	Ergonomics and Human Factors
7. Operations Engineering & Management	Production Management (including Production System Design)
8. Supply Chain Management	Logistics
9. Engineering Management	Project Management
10. Safety	Sustainability
11. Information Engineering	Computer and Information Systems
12. Design and Manufacturing Engineering	Automation
13. Related Topics 13.1. Product Design & Development 13.2. System Design & Engineering	Product Design

1.2 Problem Solving based Learning and Project based Learning

Talking about Project based Learning is a natural way to talk about John Dewey but he did not create any concept of Project-Based Learning. However, he is one of the most recognized thinker who put the concept of ñlearning by doingò on the table and helped to change the education understanding. Right now, Project-Based Learning (PBL) is a philosophy and systematic way to teach that is used around the world.

PBL can be define as a systematic teaching method that engages students in learning knowledge and skills through an extended inquiry process structured around complex, authentic questions and carefully designed products and tasks (BIE, 2017). Typically, PBL process includes five phases: (1) preparation, (2) setup, (3) start-up, (4) execution and (5) end. It can be implemented in single course but it is frequent to take 3 or 4 semesters to complete the process.

According to Wang J., Yap C.S. and Goh K. (2017) today a several engineering education challenges must to be faced in order to response to competitive environment:

1-Engineering curriculum has been designed to be highly structured, locked into overly long, serial course sequences.
2. The curricular organisation has been institutionalised within an engineering science model of engineering, and is delivered within academic cultures that clearly conform to the scientific research enterprise.
3. Engineering schools seem to convey to all students the idea that mathematics is the language of engineering.
4. Engineering schools have done a much better job teaching analysis than they have done teaching design.
5. Engineering schools conduct the engineering education enterprise in an environment in which each studentôs performance is largely assessed in individual terms, often in styles that encourage each student to see himself/herself as being in competition with her peers.

There is a lot of study cases published about PBL and it is normal to list some benefits about the education process (Lima Rui et al, 2017):

1-Teachers and students start with a problem and focused on their solution.
2-Knowledge and technical skills are linked with reality.

3-High interaction between teachers, students, sponsors (companies, communities, etc.) and staff from other departments.
4-High interaction with people in multi-cultural enviroments.
5-Engineering education research recognized by peers.
6-More opportunities for staff development.

On the other hand, Problem Solving based Learning (PSBL) is another approach that it is used so much in engineering education. According with Yih Chyn M. and Huijser K., (2017), Howard Barrows is one of the key pioneers of PBL and has written extensively about the essentials of PBL since it was developed and first applied to medical education in the 1960s. Barrows gave his point of view about what a problem is: ñA problem occurs when the knowledge and/or actions you should undertake to accomplish an objective are not obvious or known.ò (Yih Chyn M. and Huijser K., 2017)

Yih Chyn M. and Huijser K. (2017) set what Problem Solving based Learning is as a method, according with Howard Barrows thought and defined before his passing on March 25th, 2011 in a last talking with Megan Yih:

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> **Problem-Based Learning Essentials**
> by Howard S. Barrows
> *Authenticity*
> Problem-based learning should be in the contexts of the environment where the learner will function after graduation. The problems presented to learners should be those that the learners will encounter in their work. The behaviours and skills required of learners in the learning process should be only those used and valued in their career. The problem-based learning process itself should parallel the process followed by expert professionals encountering problems in the learnersô career field.
> *Problems should present as they do in the real world and permit free inquiry by learners*
> The problems should be in the form they will appear to the learners after graduation with only the information that would be initially available. The learner should be able to inquire about the problem through free inquiry, as occurs in the real world, to find the facts needed to build the problem into a case.
> *Problem-solving skill development*
> With problems that present as they do in work and designed to permit free inquiry, the learners should practice and develop effective and efficient problem-solving skills guided by tutors who understand and can facilitate the reasoning processes required.
> *Student-centered*
> The learners should be able to recall and apply the unique knowledge and skills they already possess to an understanding of the problem they are working with and determine what they each need to learn to more effectively understand and manage the problem. When the learners can build on the knowledge they already have, the understanding and recall of new information is enhanced.
> *Self-directed learning skill development*
> Under the guidance of the tutor, learners should become responsible for their own learning, able to determine what they need to learn and how to get the knowledge they need from a world of available resources (texts, libraries, journals, online, consultants, faculty experts). Since new knowledge is developed in all fields and new problems appear in the workplace, it is essential that the learners are able to update their knowledge and skills effectively and efficiently to meet new challenges on a just-in-time basis.
> *Integrated knowledge*
> In their self-directed learning and problem work, the learners should obtain information from all the subjects or disciplines related to the problem. They should be able to integrate that information to obtain an in-depth understanding of the problem and a fuller appreciation of the interrelation of information from all disciplines in contributing to the understanding and management of a problem.
> *Small group collaborative learning*
> Contemporary work of necessity involves teamwork, and graduates must learn how to work effectively in teams both as leaders and followers as the task requires, capable of learning from and teaching each other. The learners develop these skills through small group work with peer and self-assessment.
> *Reiterative*

Following a period of self-directed study, what was learned must be applied back to the problem at hand and not just described. The learners must critique and revise their prior reasoning and knowledge about the problem and revise their decisions and inquiry on the basis of new learning through discussion and argumentation based on what was learned.

Reflective

When the learners have completed their problem work, they must review what they have learned and discuss its potential application to other problems. They need to reflect on what they had learned in prior, relate problems and consider what abstractions and generalization might be developed. Developing a concept map that relates information acquired to the decisions about cause and management of the problem may often reveal errors in reasoning and holes in the learnersô knowledge and understanding of the problem.

Self- and peer assessment

This should be practised at the end of every problem, where each learner assesses his/ her own gain in knowledge, problem-solving skills, self-directed learning skills and interpersonal skills. Following such a self-assessment, the others in the group must then assess that learner. The ability to assess oneǿs own performance and provide constructive feedback to others is an essential lifetime career skill. In problem-based learning, this developing skill can be used as a more accurate and detailed assessment of each learnerǿs progress in the curriculum.

Skilled tutors

Trained tutors are skilled in facilitating learners as they problem-solve, identify what they need to learn, carry out self-directed learning, apply what they have learned back to the problem, work as a team and carry out peer and self-assessment as required. These are tutors that will not directly teach the learners, provide them with the information they need or tell them when they are wrong. They are the backbone of any problem-based learning curriculum and need to be specifically trained as this is a new and challenging teaching skill. The learners should not be dependent on the tutor for their learning, but on themselves.

Foundational

In problem-based learning, the learners are expected to become responsible for their own learning, determining what they need to learn, and to have the time to develop problem solving and self-directed learning skills accessing the worldǿs rich knowledge from many disciplines. The practice and development of these skills is central to their learning as is the acquisition of integrated information, not for its own sake, but for its usefulness in application to career problems. The learners are assessed with performance-based exams that require them to apply what they have learned to the solution of problems in their chosen field of practice. These learners should not also be asked to learn in another part of the curriculum in separate subjects, where teachers provide them what they need to learn in lectures and reading assignments and expect learners to regurgitate that learning on exams that assess only their skills in memorising the required content.

This is a totally different epistemology that is not aimed at producing a problem-solving, self-directed learner, who can assess his/her own learning needs and work effectively in teams. In addition, the demands of such a memorization/test curriculum rob the learners of the self-directed learning time they need. Combining problem-based learning with traditional learning confuses both learners and teachers and weakens the effectiveness of problem-based learning. When problem-based learning is the foundation of the curriculum, it is easy to incorporate lectures, seminars and laboratories for their own unique value and in a way that complements the problem-based learning approach.

January 13, 2002 (Source: H. S. Barrows, personal communication, January 13, 2002)

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As we can see, Problem Solving based Learning fits very well with the ñengineering thinkingò, which starts with the well definition of a problem that requires the basic sciences application and a lot of times the technological development. Marilyn Lombardi (2007) lists the following ten design elements that PBL achieve perfectly:

1. Real-world relevance
2. Well-defined problem
3. Sustained investigation
4. Multiple sources and perspectives
5. Collaboration
6. Reflection (metacognition)
7. Interdisciplinary perspective
8. Integrated assessment
9. Polished products

10. Multiple interpretations and outcomes

2. Searching for an integration of PbL and PSbL: the case of Industrial Engineering Department at University of Costa Rica

The University of Costa Rica is located geographically in Central America and is a state institution whose origins date back to 1843.

The University of Costa Rica is among the 500 best universities in the world according to the QS ranking. It passed in 2018 from the 471-480 range registered in 2017, to the 411-420 range, improving 60 positions. The Department of Industrial Engineering began operating in the year 1970 with the B.Sc. and in the year 1973 the program of M.Sc. In 2015, the Ph.D. in Engineering with one of its emphasis in IE.

Currently the program is taught in three locations or regions (San Pedro, Alajuela and Western Region) and there are approximately 2500 students and more than 120 new professionals per year and more than 90 projects linked to industry and society annually.

The program began to implement a PBL-centered approach as a way to get the student to experience reality and get to know the industry from the early university years. In all the courses, a project related to the theme of the course and related to problems of the industry was carried out. However, this was implemented without a framework and without a systematic approach.

The results of this non-systematic way of implementing PBL had very good results. Students and teachers obtained a great sense of reality and also "learning by doing" was a principle that made sense.

However, the management of the projects was not systematic nor was it the best way to define and approach the problems that were intended to be solved. This caused that in some courses the results were spectacular and in other cases the results were barely acceptable. This lack of consistency detracted potential from the PBL strategy and this led to the search for new ways of approaching.

Another undesirable consequence was the project completion time. In the course projects (95% of the courses had a project as an evaluation instrument), although the urgency to deliver on a certain date by the students was prominent, the completion times were too long, very likely provoked for the lack of rigor in the use of project management methodologies and the lack of systematization when defining the scope of projects. It was common for students in a semester to request extensions of time and in graduation projects the times also lengthened in many cases up to 100%.

With the arrival of accreditation processes, in this case with the Canadian Engineering Accreditation Board (CEAB is similar to ABET) new opportunities came to rethink the pedagogical practices and the education model. One of these opportunities was the best definition of courses in which the PBL approach can obtain better results and also the strengthening of contents to achieve a better management of the projects. The creation of the body of knowledge of project management with certificate of skills gave an excellent opportunity to restructure the PBL model.

It was then that courses were defined with a project focused on a specific topic, courses without a project and courses with an open-ended project and integrating knowledge and skills from different courses with related topics. In addition, the proposal and management system of graduation projects was restructured to cut the completion times and the scope of the projects.

The improvement has been remarkable since then in terms of the result in the training of professionals and also in the execution times that have been drastically cut back since then although they still require attention and improvement to be constantly cut.

However, the PBL method has not been documented and managed within a knowledge management concept. This introduces a risk of loss of good practices and "know-how" in a historical moment like the current one, in which there is a strong generational change with many staff members who will soon retire.

Another relevant aspect in this case is that the pedagogical practices associated with PBL have not been integrated with others equally necessary and very beneficial. In fact, this is the next step beginning with the systematization of mapping and organization of pedagogical practices that have been implemented both internally and in world-renowned universities. This includes the use of educational technologies, especially those related to virtual spaces, remote activities, both synchronous and asynchronous, as well as Massive Online Open Courses (MOOC). However, it is also necessary to formally define the educational paradigms that will govern the use of these pedagogical practices, beyond simply establishing that it is "constructivism" or "meaningful learning" or "humanism" as an educational epistemology.

On the other hand, a not systematic way of Problem Solving Based Learning (PSBL) model has been implemented in some courses to improve problem analysis skills and the search for possible solutions. Some didactic instruments used for this purpose include the analysis of cases, the development of computer applications oriented towards specific problems, the dramatization of real situations in industrial environments, the development of "real life cases" with the participation of invited professionals who work in different types of businesses and research on the use of cause and effect analysis for the definition of real problems in productive sectors of goods and services.

However, the approach of the two approaches (PBL and PSBL) in an integrated manner has not been an alternative until now, some problems of scope and product definition have been critical, especially in graduation projects. Some stakeholders have provided feedback on the development of projects and point to the need to better focus on problems that can be solved in shorter terms and with a sense oriented to the real impact on competitiveness. Likewise, entrepreneurship projects that have grown by more than 100% have marked the need to focus on engineering design, technological development and integration of tools in a context centered on Industry 4.0.

Today the integration of PBL with PSBL seems to be a potential option as a transforming axis of the program. Especially when articulating lines of development of the body of knowledge concatenating different topics and achieving that some courses are those that use the PBL as a method to integrate the knowledge and skills acquired in other courses of the program.

In this competitive and social context of major changes in the academic program driven by the needs of productive sectors in the Industry 4.0 era, the main changes that have yielded plausible results in UCR are centered on pedagogical strategies rather than curricula content, which is simply a tool for design, technological development or data analytics approach for problem solving. PBL and PBSL become crucial teaching and learning methods but must be complemented with an updated laboratory infrastructure and staff development as an essential platform.

For example, in terms of content, the program should be strengthened in the field of technology integration applications and virtualization, however, having new courses designed with these contents and laboratories to support it will be insufficient if the pedagogical practice does not change and more than anything oriented to the creative solution of problems and in an interdisciplinary way. This is where the integration of PBL and PSBL can provide a great solution.

But not only the pedagogical, didactic and laboratory field is essential for the alignment of the program with the needs and world trends (especially of the Central American country and area). The flexibility of the program and internationalization should be pillars of the new model. Figure 3 shows the strategic approach of the program to guide actions towards this purpose.

In this figure it can be seen that the strategies require a technological but also organizational alignment. The path must be drawn towards the approach by systematic processes, the management of the organizational culture and the management of international collaborative relationships. These are the next challenges in the Industrial Engineering Department of the University of Costa Rica.

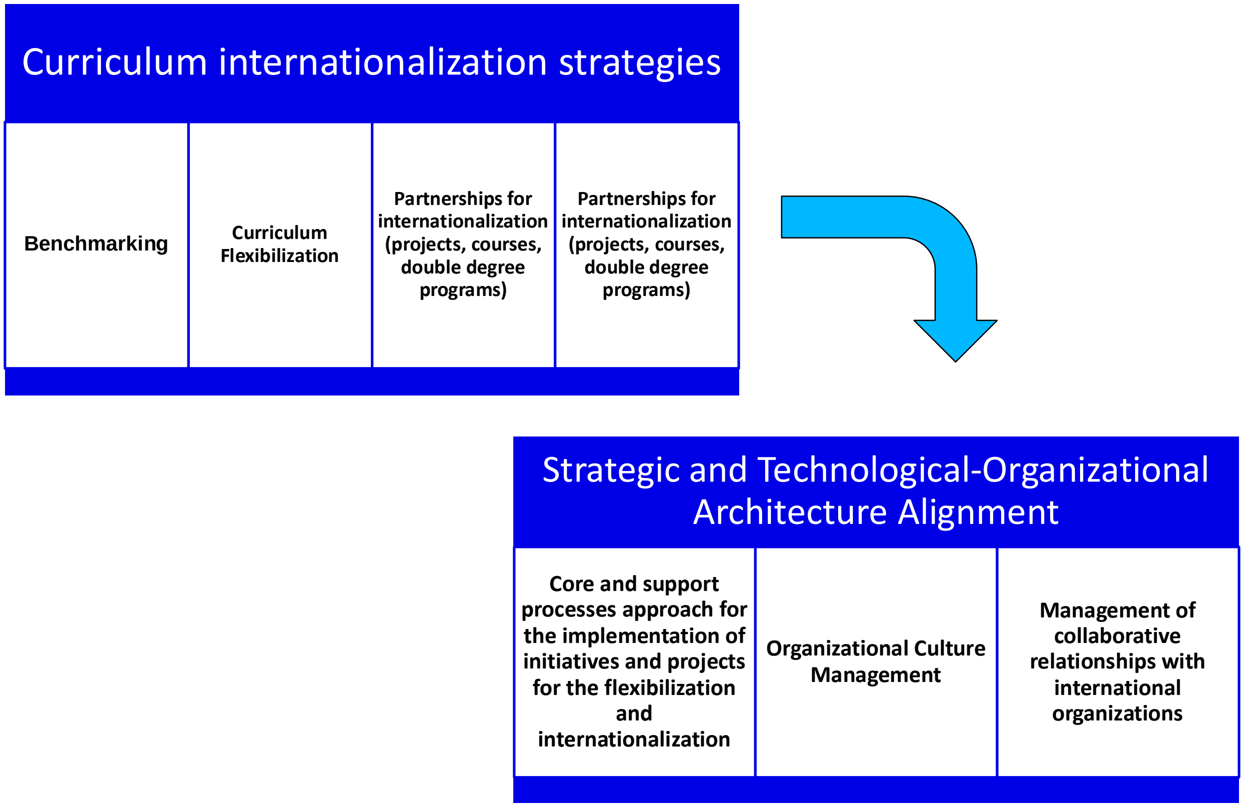

Figure 2. IIE Department Model for Curriculum Flexibilization and Internationalization

Conclusions

Conclusions can be separated on two analytical dimensions: 1-Significative Learning for life and 2-Technical Skills for Industrial Engineering Design. In the dimension number 1, PbL and PSbL must to be articulated between them and linked with real life situations. These should be essentially applied in a multi-disciplinary environment and with a strong follow up in order to get practical results. On the other hand, for technical skills reinforcement, PSbL must be mandatory and PbL a practical way in order to aim goals with pragmatism and tangible results orientation.
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Biography

Eldon Caldwell, full professor (Cathedraticus) at University of Costa Rica with over 25 years of teaching and research experience, is "IEOM Outstanding Service Award" and recently selected (2018) as Fellow of the Industrial Engineering and Operations Management Society, IEOM, USA. After his Bachelor and Master degree in Industrial Engineering at University of Costa Rica, he obtained several M.Sc. degrees (MBA, Health Systems, Social Marketing, Operations Engineering) and finally a Ph.D. in Industrial Engineering at the University of Nevada, USA. In addition, he is Dr. Sc.(in fieri) in Automation and Robotics at the University of Alicante, Spain; and Dr.Ed.(in fieri) in Education at the University of Costa Rica, CR; and currently he is serving as Dean of Industrial Engineering Department at University of Costa Rica and he is member of IEOM Society Global Council. His research interests include smart, lean and cognitive systems, robotics, cyber-physical systems and intelligent technologies for educational systems implementation in workplace for equitable employment of people with disabilities. Contact: eldon.caldwell@ucr.ac.cr