A New Approach in Engineering Education: The Design-Centric Curriculum at the University of Brasília-Brazil

Márcia Longen Zindel, João Mello da Silva, João Carlos Félix de Souza, Simone Borges Simão Monteiro, Edgard Costa Oliveira

***Abstract*— The global market demands engineers that have strong engineering fundamentals, a multi-disciplinary system perspective, good communication skills, the ability to work in teams and the capability of handling the challenges imposed by design problems. Taking this into account, the Production Engineering Undergraduate Program at the University of Brasilia has introduced an alternative learning approach, the design-centric curriculum in March 2009. The design centric curriculum is an alternative learning approach that encompasses knowledge of various disciplines and focuses on development of design thinking and project based learning. This article aims to provide an overview of the curriculum implemented.**

***Index Term*-- Design-centric curriculum, design thinking, project based learning, learning in engineering education.**

I. Introduction

New learning methods have become research objects at many educational institutions worldwide. Educators are concerned about the traditional methods, wondering if students only participate as passive agents and present low knowledge retention.

In order to evolve from a traditional approach to an objective approach that seeks to help students retain more knowledge, many universities have developed design policies, with the implementation of a design-centric education. The design-centric curriculum may be structured in a way that it enables graduate students to deal with real problems. This approach is taken within a systemic view, thus engineering activity is seen as a professional interaction with the various environments, where the students' performance interferes in the process and is also being affected by it. The educational proposal aims to ensure an articulated view of the characteristics of professional practice and different areas of knowledge, and also tries to understand the multiplicity of key aspects involved in problem-solving with a special emphasis on project activities.

The University of Brasilia undergraduate program Curriculum in Production Engineering is structured within problem based learning as a general teaching approach, in particular the Project-Based Learning-PjBL. The program started in August 2009 and presents project majors from the 4th through the 10th semester. Students develop real life projects with topics proposed by external agents, such as government agencies and industry. This approach stimulates learning by bringing together project proposals to external agents and because in the market situation student performance will be evaluated in the light of such real problems.

The curriculum's innovation seeks to form professionals with the expertise to work on a project-based approach, which is conducted on a cumulative basis during the course of the undergraduate program. This focus on PjBL alongside the program allows a more technical basis of the students' knowledge, especially in the development of the graduation projects which take place at the end of the course.

This paper presents the University of Brasília Production Engineering Undergraduate Curriculum Program, seen under the perspective of a new teaching approach, by using the design-centric curriculum model.

II. Methodology

The set of production systems projects within the University of Brasilia undergraduate program in Production Engineering (CGEP/UnB) aims at creating and aggregating value in the students´ education, through an articulated set of activities, involving sustainable project methodologies, specific technical contents of the coursework and the application of key methodological and technical aspects for the solution of real problems brought on by external agents.

The first step was to characterize the CGEP/UnB as a system of human activities (SAH), of which every student is the product and the customer. In addition to the concise text that SYSTEM is a set of interrelated elements, concepts of various authors and institutions such as Ackoff (1996) [1], Bertalanffy (2006) [2], Checkland (1981) [3], (DAU 2001) [4], and Turchin (1977) [5], were taken into consideration.

In terms of models, systems were put into two major segments: those that are within the limits of human knowledge and those that transcend such knowledge. In the space of human knowledge, two broad classes were considered: (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 a living element in a biological sphere, and (ii) systems arising from the explicit action of the human being. As part of the latter class, the SAHs arise when human consciousness itself becomes an explicit part of the system origin (Checkland, 1981) [3]:

Ackoff (1996) [1]: conceptualizes a purposeful system as a system that:

"…can produce the same outcome in different ways in the same (internal or external) state and can produce different outcomes in the same and different states. Thus a purposeful system is one which can change your goals under constant conditions; it selects ends as well as means and thus displays will. "

The formation of value, embracing both the generation and the conformation of value and the appropriation of this value to stakeholders, internal and external to the SAH, which may affect or be affected by SAH is taken as the main purpose of any SAH (Gharajedagui, 2006) [7]:

Ackoff and Guarajedagui (1996) [1]: characterized four types of systems as a whole (in a systematic view), where each part has a purpose, as in Figure 1. In this characterization, the concept of social system´s - the whole and the parts have a purpose - was applied to SAH.

SYSTEM	PURPOSE	
	WHOLE	PARTS
DETERMINISTIC	NO	NO
ANIMATED	YES	NO
SOCIAL	YES	YES
ECOLOGICAL	NO	YES

Fig. 1. Types of Systems

The consideration of sustainability led to sustainable value formation. The basic premise that SAHs should be part of sustainable ecosystems gives rise to the category of "Sustainable Systems of Human Activities - SSAHs." Thus, the CGEP/UnB has mainly to convey to students the academic background that will lead to professional competence in dealing with SSAHs, as well as help in the transformation of SAHs into SSAHs.

The concept of knowledge, according to Bicudo (2000) [8], where knowledge is seen as an activity, is being used in this approach: time, temporality and movement, in the sense that the objects order of coexistence (here, there) is not dissociated from the order of succession (before, now, after).

As a synthetic indicator of future performance and the desired SSAH, the value formation can then be explained as a function of positioning time/space of states resulting from the behavior of SSAH; these positions translate into Trajectories of Excellence crossing a Diversity of Value Formation Spaces (transition space) under Different Perspectives of Time (transition time).

The understanding of what is "Here," "Next" and "Far", which correspond to the Order of Coexistence in any space, requires the concepts of scope, context and environment. This conceptualization, in turn, has referred to one of the first categorizations applied to systems by Guarajedagui (2006) [7], which separates the variables associated with elements of any system, including SSAHs into two main groups: the variables that can and that cannot be controlled by the system as a result of their actions. Control means that the system´s actions are necessary and sufficient to produce desired outputs in sets of interactive variables.

Continuing the movement from outside to inside, as it approaches the boundary of the system; proximity plays a part in influencing variables to become confluential. Confluence, taken as an action in terms of co-participation, in comparison with the concept of influence, means that the action, though not enough for the desired outputs, is a co-producer able to leverage over its original degree of sufficiency in the vicinity of the system. Ultimately, the intersection of the co-produced actions may result in a sufficient degree to become confluent actions in actions under joint control, and not just individual, involving necessary and sufficient conditions for desired outputs of all systems involved.

The transition space associates "confluence" to "close", "current location" to "here" and "influence" to "distant". The "environment" is associated to the "limits of the far" in terms of interest. Taking as reference the above concepts, it is possible to discern four sections for the characterization of systems in action:

Scope: actions under control of the system, necessary and sufficient for desired outputs.

Context: Co-production.

Confluence: actions of co-production, necessary, and leveraged by the proximity increasingly sufficient for the desired outputs. Ultimately, the intersection of the co-producer´s confluent actions can result in actions under joint control, encompassing necessary and sufficient conditions for the desired outputs of all or part of the system´s involved co-producers.

Influence: the actions of co-production, necessary and not sufficient for desired outputs, not leveraged by proximity.

Environments: SSAH actions without control regarding the desired outputs.

Understanding "Before", "Now" and that "After" correspond to the order of success in space horizons requires the conceptualization of modeling, which includes generalizations of the time dimension as time, complexity and orientation.

In Projection Horizon Modeling, the future is treated as a continuation of the past, based on intelligent platforms, which are characterized by having integrated data quality and are being stored in an intelligent way, an arsenal of analytical models and a set of intelligence tools. Projections are produced by composition (bottom-up orientation) from evidence of the past, with its wide application in the treatment of short-term situations involving mainly cause and effect. Based on intelligent platforms, projections usually start to get fuzzy as the deadlines are longer, more complex situations in terms of cause-effect data and the compositions with higher levels of abstraction in relation to the original basis. The whole of the resulting compositions has less to do with the original parts considered. The reaction is the essential attitude in the projection modeling, which takes as its starting point the understanding of reality that has already happened.

In Vision Horizon Modeling, the near-by future is envisioned from more distant future visions. A complex view of the long-term future is taken into account as a compact reference to be decomposed (top-down orientation) for what is expected to happen in the near future. The constructions of visions of the frontiers of knowledge, to be taken as references are primarily consolidations of expertise. Visions usually begin to get fuzzy as the deadlines become shorter simpler situations and more abstract decompositions with respect to the original synthetic models. The parts resulting from the decomposition have less and less to do with the original whole considered. The essential attitude about the vision modeling is imagination, starting from the knowledge of reality that has not yet happened.

In the Prospection Horizon Modeling, projection and vision are combined, with (i) the composition of which were obtained in different futures for assembling the parts from current analytical data basis, and (ii) the decomposition of all parts obtained in a different future, closer in the disassembly of this more distant future. This horizon, which constitutes the bridge between the other two, focuses on the overlapping and merging of the results of the bottom-up and top top-down approaches of the projection and vision horizon modeling. Scenarios are developed in the Prospection Horizon Modeling. Adaptation is the essential attitude about the prospection modeling.

The temporal transition associates "historical past" to "before", "perception of present" to "now" and "desired future" to "after." As shown in Figure 2, the space-time positions should seek Trajectories of Excellence, regarding ends and means and performance indicators.

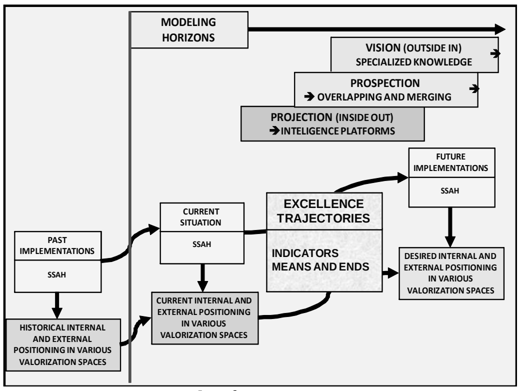

Fig. 2. Value formation in SSAHS

III. THE ROLE OF DESIGN CENTRIC EDUCATION IN AN ENGINEERING CURRICULUM

A survey conducted by Lang, Cruse, McVey and McMasters (1999) [9], about the industry expectations regarding new engineers, has indicated some key concerns like team work skills, capability of handling the challenges imposed by design problems, technical versatility (multi-disciplinary), ability to solve problems from a systems-level perspective, effective communication, demonstration of social responsibility, and a broader perspective of the topics that concern their profession such as social, environmental and economic issues.

The predominant model of engineering education is graduating engineers with solid knowledge of fundamental engineering science and computer literacy. However, they are unable to put these skills to practice. As a result, students and industry are calling for significant changes of the current philosophy and delivery of educational outputs. Engineering programs are now required to revise program and course structures, plus teaching methods, in order to help their graduate students to acquire the industry-desired skills and qualities in the future. According to Mills and Treagust (2003) [10], the critical issues that need to be addressed are:

1. Engineering curricula are too focused on engineering science and technical courses without providing sufficient integration of these topics or relating them to industrial practice.

2. Current programs do not provide sufficient design experiences to students.

3. Graduates still lack communication skills and teamwork experience and programs need to incorporate more opportunities for students to develop these skills.

4. Programs need to develop more awareness amongst students of the social, environmental, economic and legal issues that are part of the reality of modern engineering practice.

5. Existing faculty lack practical experience, hence they are not able to adequately relate theory to practice or provide design experiences. Present promotion systems reward research activities and not practical experience or teaching expertise.

6. The existing teaching and learning strategies or culture in engineering programs are outdated and need to become more student-centered.

The solutions generally proposed to overcome most of these issues involve a fundamental redesign of the curriculum in engineering programs and teaching methods. The curriculum in engineering programs is facing the challenges of equipping engineering students with the skills and knowledge required to be successful global engineers in the 21st century. According to Savage, Stolk and Vanasupa, (2007) [11], enabling students to practice self-directed learning, to find solutions to design problems that are sustainable, and to recognize that they are part of a global community are just a few of the many educational goals.

Undergraduate engineering educational curricula must not only prepare students to work in the rapidly changing world, but must also engage then in disciplines beyond engineering to make them better engineers and more informed human beings and citizens (Bok, 2005) [12].

While there are a number of pathways that can be taken to accomplish curricula reform, a new approach in engineering education is the Design-Centric Education. A design-centric education encompasses: multiple disciplines; focus on project development driven by clear design objectives; educating engineers to become well-equipped to lead with solving complex and multi-disciplinary problems, exposing students to real-life issues and problems, in which, students learn to recognize the problems or difficulties, formulate project objectives from the identified problems, analyze and diagnose the problems and devise a most appropriate solution. Nowadays the central role of design in engineering curriculum is increasingly recognized at various engineering courses around the world

According to Simon (1996) [13], design is the central or distinguishing activity of engineering. Design involves challenges, multiple problem representations, ambiguity, multiple solutions, and a lack of procedural and declarative rules. The integration of those elements into a design-centric curriculum requires reconceptualization of the current educational paradigm.

Currently the most-favored pedagogical model for teaching design is project-based learning. Project-based learning promotes learning around projects. Projects can be defined as complex tasks, based on challenging questions or problems, that involve students in design, problem-solving, decision making, or investigative activities; give students the opportunity to work relatively autonomously over extended periods of time; and culminate in realistic products or presentations (Jones, Rasmussen and Moffitt, 1997 [14]; Thomas, Mergendoller and Michaelson, 1999) [15]. This methodology also involves real-life simulations, critical thinking, goal setting, problem solving, and collaborative skills.

The Project based learning experience begins with the students being introduced to a set of user defined performance requirements (Savage, Stolk and Vanasupa, 2007) [16]. A project plan is establish to guide students through the process. Helle, Tynjälä and Olkinuora (2006) [17], point out the characteristics applied to the project-based learning experience:

(1) [Projects] involve the solution of a problem; often, though not necessarily, set by the student himself [or herself].

(2) They involve initiative by the student or group of students, and necessitate a variety of educational activities.

(3) They commonly result in an end product (e.g., thesis, report, design plans, computer program and model).

(4) Work often goes on for a considerable length of time.

(5) Teaching staff are involved in an advisory, rather than authoritarian role at any or all of the stages—initiation, conduct and conclusion (Helle, Tynjälä and Olkinuora, 2006, p. 288) [17].

Project based learning provides the contextual environment that makes learning exciting and relevant. It provides an opportunity for students to explore technical problems from a systems-level perspective and to develop an appreciation for the inter-connectedness of science and engineering principles. (Savage; Chen and Vanasupa, (2007) [11]. Furthermore, a project, based on design problems, gives students a contextual environment that makes learning relevant and focused.

Project based learning methodology also encourages and develops collaborative work plus team work, improves retention and student satisfaction and enhances design thinking. Besides, the results already obtained demonstrate PjBL's value in increasingly authentic design scenarios that typically include participation across disciplines, as well as across geographical and temporal boundaries (DYM, 1999) [18].

IV. DISCUSSION: PRODUCTION ENGINEERING DEGREE AT CGEP/UnB

Taking the Value Formation in Model, presented in section II, as reference and under the general background of the design-centric education in engineering, the curriculum of the CGEP/UnB is bound by professional requirements, under the responsibility of the Brazilian National Council of Engineering, Architecture and Agronomy (CONFEA), as well as academic guidelines established by the Brazilian National Education Council (CNE).

On the professional side, the main document is a resolution published in 2005, which established the following professional areas for Production Engineering: (i) Physical Production Processes Engineering; (ii) Quality Engineering; (iii) Ergonomics; (iv) Operations Research; (v) Organizational Engineering; and (vi) Engineering Economics (CONFEA 2005) [19].

On the academic ground, it follows both, the national curriculum guidelines CNE (2002) [20] and the minimum required workload for engineering degrees (CNE 2007) [21]. Under these resolutions, the students must accomplish requirements encompassing compulsory, elective and free choice course subjects, as well as complementary activities, in a total of 3.600 hours. It is required that the students have a minimum of 160 hours of internship, as well as synthesis and integration activities, including a graduation project.

As shown in Figure 3, the contents of the Synthesis, Integration and Entrepreneurship (Space Block S), constitutes the backbone of the CGEP/UnB. It takes into account six spaces of Value Formation: S1 - Core Concepts; S2 - Production System Projects; S3 – Supervised Internship; S4 – Graduation Project 1; S5 - Graduation Project 2; and S6 - Complementary Activities. The other required blocks are: (i) Mathematics, (ii) Physics (iii) Chemistry (iv) Information Systems (v) Technology (vi) Relevant Subjects: Sociology, Economy, Political Science, Sustainable Development, (vii) Production Engineering; and (vii) Free Choice Contents.

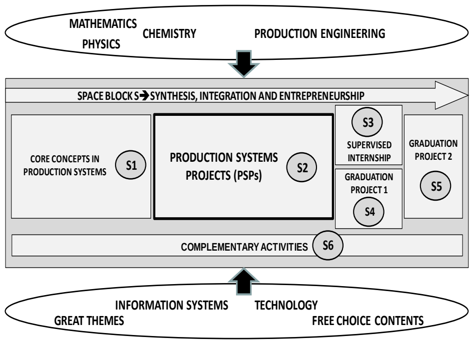

Fig. 3. Value formation space block structure

The Core Concepts in Production Systems (S1) covers basic concepts of process engineering, value formation, cognitive ergonomics, human behavior and sustainable project methodology. The seven courses of the Production Systems Project, PSP1 to PSP7 (S2) they are anchored in project based learning methodology. The Graduation Projects (S4 and S5) encompass Graduation Project 1 and Graduation Project 2. The Supervised Internship (S3) consists of field work in the real world of Production Engineering. In order to reconcile the Graduation Project with the activities carried out in the field, the Supervised Internship should preferably be associated with the discipline Graduation Project 1 (S4). The Complementary Activities (S6) encompass the student's activities in scientific initiation, multidisciplinary and community projects, as well as participation in technical visits, events, extension projects, prototype development, youth companies and other entrepreneurial activities.

When in regime, in each semester of the Space S2, a total of 300 students are expected, to be allocated into seven Projects (y, z), where y represents the project number (1 to 7) and z stands for the corresponding semester of the normal coursework (4 to 10). Considering each of these projects also as a space of value formation, the following methodological and specific technical contents of the coursework for each Project (y, z) have been established: (i) P1= Project (1,4)→Methodology: PSP1; Technical Content: Probability and Statistics, (ii) P2= Project (2,5)→Methodology: PSP2, Technical Content:

Engineering Economics; and Information Systems in Production Systems; (iii) P3= Project (3,6)➔ Methodology : PSP3, Technical Content: Operations Research in Engineering 1; (iv) P4= Project (4,7)➔Methodology: PSP4; Technical Content: Manufacturing Processes; Production Planning and Control; Simulation Systems; and Hygiene and Health at Work; (v) P5= Project (5,8)➔Methodology: PSP5; Technical Content: Quality Management; (vi) P6= Project (6,9) □ Methodology: PSP6; Technical Content: Product Engineering; and Logistics and Supply Chain; and (vii) P7= Project (7,10)□ Methodology: PSP7; Technical Content: Strategic Management.

As shown in Figure 4, each of the projects P1 through o P7 of the Space S2 of the curriculum are based on four major value formation spaces, called anchors: (i) Methodology and project sustainability courses, (ii) technical content of courses, (iii) real problems plus external agents, and (iv) other courses with specific topics of interest in the project.

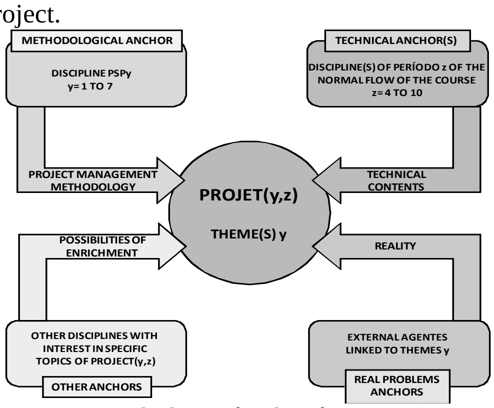

Fig. 4. General scheme of anchors for project (y, z)

Figure 5 explains the dynamics of the interaction of the value formation spaces S1 through S6. Besides showing the interactive nature of learning in spiral, present in the seven projects of space S2, the possibility of including complementary activities (Space S6) projects not only in P1 through P7 and their PSPs, but also in other areas of the backbone of the program, is explained by repeating the symbol of S6 in all other components.

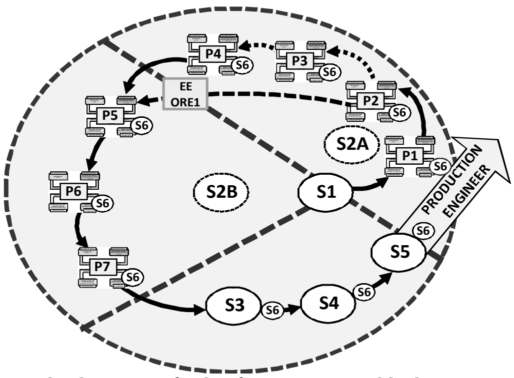

Fig. 5. The dynamics of value formation space blocks S1 to S6

The projects of Space S2 were divided into two groups: P1 through P4 in S2A and P5 through P7 in S2B. Also in S2, the arrow connecting P2 to P5 means that PSP2 releases projects P5 through P7 for students that have attended the courses of Economic Engineering (EE) and Operations Research for Engineering 1 (POE1), shown in the rectangle on the arrow. Thus, only those students with stronger knowledge in economic and financial evaluation (EE) and mathematical modeling (POE1) can participate in P5, P6 and P7.

Teachers assigned to the PSP courses are being allocated according to the matrix structure:

- Coordinator: overall coordination of the discipline.
- Project Advisor: project management of each team.
- Functional Advisor: functional aspects applicable to projects of all teams.
- Methodological Tutor: methodology for Sustainable Projects.
- Behavioral Tutor: human behavior in teamwork.
- Technical Tutor: integration of the technical content of projects (anchor course).

The PSP1 course, initial basis for the implementation of the PSPs, is the only one of seven PSPs in the flow of the program that, besides the methodological anchor, has content in systems and models, human interaction, cognitive ergonomics, data base search, technical standards for reporting, team behavior and methodology of sustainable projects. With the basic premise of the importance of business intelligence platforms for all PSPs, each PSP1 class is being directed towards initiating intensive use of the platform available in terminals of a specific project classroom and in terminals of the Faculty of Technology's Computer Science Central Laboratory.

The course "Probability and Statistics – PE", as an anchor for technical content of PSP1, provides the main theoretical foundation on which projects will be based. In addition to probability theory and statistics, the specific class of PE for students of the CGEP/UnB is also being directed towards the intensive use of the business intelligence platform in its class and homework activities, preferably using real databases.

The vision of the reality can be obtained directly from the external agents or indirectly through access to databases of public and private entities. In both, direct and indirect access, priority should always be given to the use of business intelligence platforms.

The outputs of production systems can be manufactured goods or services. The services are more difficult to be measured than the goods, but their assessments are associated with the expectations and perceptions of the customers. The construction of a curriculum for an undergraduate course can be considered a process of production services in education, specifically the process of production of knowledge acquisition by the student by means of PBl and PjBL approaches. See Figure 6.

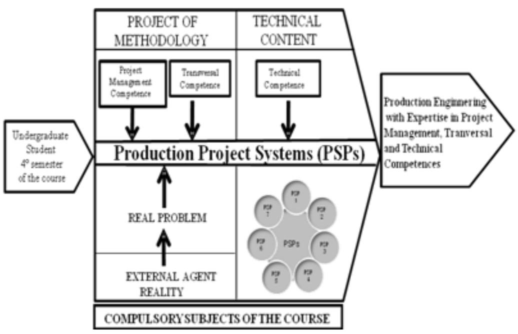

Fig. 6. Process of production of knowledge by means of PBl and PjBL approaches in Production Engineering Course at UnB.

There are inputs and outputs in all production processes. The input in the process of PSP curriculum is the undergraduate student that frequents the fourth semester of the regular course flow. The proposal for this new curriculum provides as output the production engineer, with expertise in project management, as well as transversal and technical competences that are acquired with the practice of resolution of real problems deriving from external agents (OIT, INSS).

Tobin et al. (1990) point out that the projects must be attractive enough to have the total commitment of the project team in the resolution of the real problem, in order to promote the learning of students. They must understand what they are doing in the group and in the class activities. The responsibility of the teacher is to adopt a role of facilitator in an environment that will encourage student learning and knowledge acquisition.

V. CONCLUSION

Many universities have based their curricula programs on Design-Centric Education approaches for engineering education. The project based learning is a method for Design-Centric Education and it was described in this article how the University of Brasília Production Engineering Course was designed based on these views.

PjBL educational and research outputs are highly required nowadays by the professional market of production engineering, which seeks professionals who come equipped with more than just technical knowledge, a market which demands collaborative attitude, a strong grip on project management, problem-solving skills, social responsibility, economic expertise, development abilities, plus social and environmental issues management, to name just a few.

The proposed model has gained satisfactory results in the teaching/learning process for the undergraduate course of production engineering. Similarly, the results presented in this paper show, that by its simplicity or technical inability, universities cannot anchor institution development space. Although, at this stage, it is not the main concern of the faculty, these results affirm the importance of the success and continuity of the model. Evidently, the paradigm shift from the project implementation model, as any change at any level and in any institution may represent a barrier to its continuity. This resistance comes from both the faculty with participation in classroom and guidance to groups, as well as students who show difficulties in adapting to working on projects, in the division and distribution of tasks by teams and, mainly, in the evaluation methodology of presentation, proactiveness, project development work and peer evaluation.

The University of Brasilia undergraduate Program Production Engineering presents an innovative curriculum. The seven courses of Production Systems Project, PSP1 through PSP7 (S2) are centered around a project based learning methodology. Project P1 (1,4), a launch pad for a series of seven projects, was first offered in March 2011. In the first semester of 2012, the following courses were being offered: P1: Project (1,4) for the third time; P2: Project (2,5) for the second time; and also P3: Project (3,6) for the first time. It is expected that this PjBL-based approach will foster a higher quality of the University of Brasilia Production Engineering undergraduate program, contributing to student motivation and raising the student productivity to never before measured levels.

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