LEARNING ENVIRONMENTS AND PEDAGOGICAL MODEL OF AN ENGINEERING DESIGN DEGREE PROGRAM

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ABSTRACT

This paper presents the theoretical background that supports the use of project-based learning (PBL) in engineering education and relates it to the pedagogical framework implemented in the new first cycle degree program *Technology and Product Design* offered by the University of Aveiro. The program structure is described focusing on the learning environments used in each course of this interdisciplinary program. The purpose of this paper is to characterize this new curriculum in order to contribute to the discussion about engineering education pedagogy with a complete program implementation experiment. Issues like courses architecture and scope, assessment, student/teacher ratios and group sizes are addressed. Furthermore, students' perceptions of the learning environments is investigated and compared with their learning results. Ultimately the implications of a student-centred learning curriculum design, based on a PBL strategy, are discussed.

Keywords: Engineering design education; learning environments; project-based learning; first cycle degree curriculum.

INTRODUCTION

One of the strategic vectors of University of Aveiro is the proximity with industry, not only through the development of research projects but also through the enhancement of educational programs especially tailored to meet the needs of local companies. Among other efforts, a new polytechnic school, the *Higher School of Design, Management and Production Technologies of Aveiro North*, was established in 2004 in the north of the Aveiro district in response to a long lasting claim of the industrial associations and entrepreneurs of that region. The majority are very dynamic small and medium enterprises dedicated to the production of tradable goods (e.g. footwear, mattresses, cans, plastic and aluminium parts, metal structures, tools, moulds, etc.) mainly for exportation. They have two major educational needs: (i) the training of employees both in subject-specific skills and in methodological skills, (ii) new employees (undergraduates) proficient in product development methods and tools, capable of integrating the expert knowledge that is already in the companies and systematically help in the creation of new products, processes and services. The former was addressed by the establishment, as of 2002, of a network of Technological Specialization Programs (TSP), level 5 programs (European Qualifications Framework), which are tailored and lectured in different cities of the region according to local demand. The later was addressed with the new first cycle degree program *Technology and Product Design* offered as of 2005/2006 academic year.

The above-mentioned program belongs to the field of engineering design and provides the students with the state-of-the-art methods and tools for integrated design. Due to the interdisciplinary nature of the program and the strategic emphasis on practical competencies (supported by the necessary subject related theoretical knowledge), a student-centred learning model was implemented.

In this paper it will first be discussed the increasing relevance of design as an engineering discipline and the current engineering education theories and practices, focusing on PBL within the teaching and learning models. Then it will be described and analysed how the degree program *Technology and Product Design* is structured. The analysis is based on the following perspectives: (i) European Credit Transfer System (ECTS), (ii) disciplinary area, (iii) assessment methods and, (iv) learning environments. Noticing that some courses are in a grey area, considering a strictly PBL or lecture-based learning (LBL) definition, a PBL-LBL classification spectrum is proposed in order to clarify the learning environments used in this program.

Later on, attention is drawn to the Product Development Project (PDP) courses which have adopted a pure PBL methodology in opposition to the Quality and Control course which has adopted a pure LBL approach, and then will be described how this is translated into the classroom.

To support this, it will be presented a study carried out in order to gauge student motivation, to understand the reasons behind the high dropout rate and investigate students' perceptions in relation to the PBL spectrum of the degree program. Data collection was based on a questionnaire developed by Tenenbaum et al. (2001) that was completed by the students of three courses (PDP II, PDP IV and Quality and Control) at the end of the second semester of the 2010/2011 academic year. The purpose is to obtain a view of students' perceptions of the presence of constructivism features in their learning environments. Findings are presented and compared with Dochy et al. (2005) and Gijbels et al. (2006) results. Furthermore, this analysis is crossed with the assessment results in these three courses.

The paper concludes with a discussion on the implications and challenges of the program architecture and practice on both teachers and students, seeking to optimistically embrace the future work needed. Implementing an inductive teaching and learning approach based on constructivist theory/philosophy requires a cyclical process of implementation and evaluation, which is a very demanding task for faculty.

Engineering Design

Engineering design (also called product design or product development or integrated design or a combination of these terms) is still seen by the majority of Universities as a process belonging and constrained by each of the major engineering disciplines. Mechanical, electrical, chemical, among others engineering disciplines have gained over the last century their own body of knowledge and established a kind of frontier normally seen in Universities in the names of the different departments of the engineering school.

In the last two or three decades new disciplines like mechatronics or industrial engineering have emerged in response to the industry call for engineers capable of effectively combine knowledge from the traditional disciplines. In many Universities this trend originated the creation of new departments or units dedicated to research and education of these new interdisciplinary fields of engineering. Today it is widely accepted that these new disciplines have produced sufficient cumulative knowledge to be considered at the same level of the traditional disciplines.

We believe that engineering design can and should be at the above mentioned status. Despite the fact that it is not easy to find in the name of University departments, there is evidence of sufficient cumulative knowledge in the field of engineering design to consider it a new engineering discipline (Devon, et al., 2004). Moreover, industry has been for a long time in need of engineers proficient in integrated design knowledge and skills (Bitzer, Burr, Eigner, & Vielhaber, 2008; Sheldon, 1988).

These arguments provide the justification for the success of recent undergraduate and graduate programs of engineering design and the general effort to increase the design content in the traditional engineering programs (Aran, 2009; Gibson, 2001; Meerkamm, Stockinger, Tremmel, & Wartzack, 2009; Roozenburg, Breemen, & Mooy, 2008; Sirinterlikci & Mativo, 2005).

Teaching/Learning Models in Engineering Education

In recent years European Higher Education Institutions put a big effort on implementing a student-centred learning model, which is one of the most important (and difficult to implement) requirements of the "Bologna Process". However, tradition, together with financial restrictions, represents a big barrier to this methodological shift. The predominant model is still the same, consisting of lecture-based teaching and final examination assessment. This model has several advantages, being the most relevant the twofold: (i) Teachers are used to this form of teaching and do not wish to change. In this model it is easier to plan and deliver the program (because there is no place for discussion in class) and it is easier to assess the students (because it is based on one or more written exams covering the content of the course); (ii) It is economically sound, because the number of students in class does not influence the quality of the course. Thus the student/teacher ratio can be much higher than in the student-centred learning model.

Being a content driven model, it emphasises knowledge (theoretical competence) over skills (practical competence). Yet, most jobs require practical competence, especially in the engineering profession. The majority of engineering students are graduating with good knowledge of fundamental engineering science, but they do not know how to put it in practice (Mills & Treagust, 2003). From an employers' perspective, engineering graduates also need to have strong communication and teamwork skills, as well as a holistic perspective of the implications of their work such as social, environmental and economic issues. None of these skills are consistently developed by the students in the traditional engineering programs.

To overcome these limitations a significant change in the current philosophy and structure of engineering education is required.

Problem-based learning goes back to the sixties, when it was first implemented at McMaster University in Canada, in Medicine Studies. Due to its success, the basic principles behind problem-based learning were then transferred to other areas, namely engineering education, in the 70's, and put into practice in Denmark, at Aalborg and Roskilde Universities, and in Netherlands, at Delft University, through project-based pedagogical approaches, both frequently referred to as PBL (Kolmos, et al., 2007).

Much has, since then, been written to conceptualize and differentiate problem-based learning from project-based learning, as often the terms are used interchangeably (Helle, Tynjala, & Olkinuora, 2006; Prince & Felder, 2006). In fact, many authors use the term problem-based learning, when actually describing project-based learning.

Barrows (1996) described the core model of problem-based learning as comprising six main characteristics: (i) PBL is student-centred; (ii) Learning should take place in small student groups; (iii) Teacher's role is that of a facilitator or guide; (iv) No preparation or study should occur before encountering the authentic problems; (v) The problems encountered are to be used as a tool to attain knowledge and the problem-solving skills required to solve the problem; (vi) Lastly, new information is obtained through self-directed learning.

Kolmos et al. (2007) states that the distinction between problem-based and project-based learning environments "lies in the perception of the curriculum component that stimulates the learning" (p.9). The author goes on to say that "problem-based learning is mostly referred to as the approach in which learning is stimulated by open-ended and ill-structured problems whereas project-based learning is interpreted as learning through an assignment or task performed by the students"(ibidem).

The main difference is then on the focus given. Whereas problem–based learning focuses on the acquisition of knowledge in narrow contextual settings, project-based learning is acknowledged to be more complex and authentic as students need to apply interdisciplinary knowledge to open-ended and ill-structured problem domains, where self-directed learning is crucial.

Literature has shown that in engineering education, project-based learning (often referred to as project work (Perrenet, Bouhuijs, & Smits, 2000)) is more adequate as it "more closely mirrors the professional behaviours of an engineer" (Mills & Treagust, 2003). However, engineering has a hierarchical knowledge structure, where missing elements will be negatively reflected in the final overall project as these cannot be compensated with other meta-cognitive skills. Much like building a house, if the basis structure is not there, the other components will not be self-sustainable. Thus, various studies (Mills & Treagust, 2003; Perrenet, et al., 2000) conclude that a mixed-mode approach seems to be more significant as it is able to conjugate industry's needs without disregarding essential engineering knowledge.

Furthermore, one cannot ignore that students have different learning styles, and teachers have also different teaching styles. As such, a balanced mixture of more "traditional" teaching and project based or problem based learning will recognize the student's individuality while meeting the current learning needs in engineering education, i.e., bridging the gap between theory and practice. It should be noted that just as the definition of PBL is ambiguous, the definition of what constitutes traditional teaching is also ambiguous.

Perrennet et al. (2000) defends that project work and courses need to be planned and integrated in a consistent design of the curriculum. Studies reveal that the implementation of project organized curricula, where projects are used as basis to structure the entire curriculum of the undergraduate courses, have been quite successful (Dym, Agogino, Eris, Frey, & Leifer, 2005). However, despite the timeframe and studies acknowledging the success of project-based learning, the group of Higher Education Institutions that are, in fact, using this methodology in engineering is reduced in number, as in most, lecturing still predominates during the first two years and the last year contemplates a capstone design course, where students are asked to apply the learnt concepts.

Recent studies in Australia focused on industry's needs and analysed to what extent engineering programs meet these needs. Scott and Yates (2002) study reveal that it is the "combination of emotional intelligence, a focused and contingent way of thinking, a specific set of generic skills as well as technical expertise" that accounts for the successful delivery of engineering projects in today's industrial world. Nguyen (1998) corroborate the idea that today's engineer is expected to possess a variety of skills and attributes as well as technical competency. It is not just a question of having sound knowledge of fundamental engineering principles, but also of being able to apply the knowledge and convert theory into practice. This diversity must be acknowledged and instilled in higher education curricula.

In the 1990's, a number of initiatives to reform engineering education were set forth. In the USA, the Action Agenda for Systemic Engineering Education Reform outlined three main goals: Goals for Teaching and Learning Methods; Goals for Curricular Content and Goals for Constituencies and Networks.

The Teaching and Learning Methods included, among others: (i) Engineering program faculty viewing themselves as mentors; (ii) Learning experiences that meet the needs of different students; (iii) Focus on active, collaborative learning, less dependence on class lectures.

As to the Goals for Curricular Content, the proposal was to restructure engineering curricula, by combining learning experiences not limited to traditional course structures, but which integrate subject matter by introducing fundamental principles in the context of applications, where teamwork, communication and group project involves problem-solving skills. In terms of Goals for Constituencies and Networks, the main idea was to maintain regular and well-planned interaction with the industry.

Twenty years later, it seems that the same goals still apply as the global learning environment in engineering is still focusing on technical competencies and disregarding non-technical competencies.

Students' perceptions of the learning environments

PBL is a learning environment based on constructivist theory, which has the fundamental assumption that knowledge is actively constructed by the learner. PBL is claimed to be very efficient in terms of students' learning outcomes, as mentioned previously. "Research shows that the way the learning environment is perceived by the students, rather than the factual curriculum, affects to a large extent how students cope with the learning environment and, consequently, their learning results." (Gijbels, et al., 2006)

A study of students' perceptions of PBL concluded that students perceive the characteristics of the problem-based learning environment as being present and of high importance for enhancing their learning (Dochy, et al., 2005).

Tenenbaum et al. (2001) empirically defined and examined key features of constructivist learning environments and developed a questionnaire that could be used by other researchers in different educational settings to investigate the presence or absence of constructivist practices. The study resulted in a survey containing thirty 5-point Likert scale questions. Seven key factors of constructivist learning environments underlie this questionnaire: (i) arguments, discussions, debates; (ii) conceptual conflicts and dilemmas; (iii) sharing ideas with others; (iv) materials and resources targeted toward solutions; (v) motivation toward reflections and concept investigation; (vi) meeting students' needs; and (vii) making meaning, real-life examples.

Gijbels et al. (2006) conducted a study using Tenenbaum's questionnaire to verify whether students in PBL perceive the learning environment to be more constructivist when compared to the perceptions students have of a conventional lecture-based environment. The results showed that the PBL students perceive it to be more constructivist when compared to the perceptions of students in a conventional lecture-based environment.

With this theoretical basis the intention is to further investigate if the same students enrolled in different courses of the same program with different learning environments perceive the difference in constructivism. Furthermore, study the impact of the learning environment, students' perceptions and course curriculum in the students learning outcomes.

TECHNOLOGY AND PRODUCT DESIGN DEGREE

The first cycle degree program *Technology and Product Design* was implemented in the 2005/2006 academic year and is 6 semesters long, with a total of 180 European Credit Transfer System (ECTS). Student enrolment takes place through the Portuguese system of access to higher education, with an average of 35 places available per year. As a prerequisite, candidates must obtain a passing mark in one of the following national examinations: Physics and Chemistry, Descriptive Geometry or Mathematics.

The main goal of this degree is to prepare professionals with the competences necessary for the innovation of products and processes, interpreting in an integrated way the interests of people, of industry, of society and of the environment.

This degree constitutes a unique educational offer, oriented towards the innovation, drafting, development and optimisation of products and processes. It articulates with other educational offers - Technological Specialisation Programs, Masters (2nd Cycle) and Doctoral (3rd Cycle) programs - in the area of Product Design and Development, and provides a range of complementary competences which extend from Design Drafting to Product and Process Engineering, either at the University of Aveiro or other Institutions. It favours the preparation of professionals with an interdisciplinary, largely technical, profile in the area of two specific branches: Production Development or Manufacturing Systems. In this paper we will only cover the Product Development branch of this degree program.

Product Development branch aims to prepare professionals in the referred area, by combining industrial design with mechanical engineering in order to offer industry skilled professionals able to participate in the initial stage of product conception and the subsequent stage of product development process. In order to accomplish this, the study plan is based on several areas: (i) Mathematics - basis for problem solving connected to the specific areas of this degree; (ii) Materials - the importance of materials in the modern world and in the development of products, materials selection, mechanics of materials and processing technologies; (iii) Mechanical Engineering - the technical and scientific aspects linked to product engineering, such as production technologies, electronics and mechatronics, components and structures; (iv) Industrial Design - the history and theory of design, methodologies, design techniques and practices, especially those resulting from the interaction between people and product; (v) Drawing and Communication -

representation techniques like drawing, 3D modelling and prototyping and communication techniques as a means to market products; (vi) Project - the use of computerised systems which support product development, product design and development methodologies and practical product development project work; (vii) Management and Innovation - the business context of product development, product strategies, the contribution of marketing, within a humanistic perspective which aims at social and economic sustainability, among others.

The degree profile arises out of the characteristics of the economic and industrial fabric of the *Entre Douro e Vouga* region (the north of Aveiro district), and the encouragement at national level for educational training tailored to meet the demands for innovation, design and development of new products and processes, able to promote an increase in the competitiveness and sustainability of Portuguese industry. This program therefore aims to prepare qualified professionals for sectors such as, the automotive industry (frames, plastics, components, etc.), metalworking, shoe and cork industries, among others.

Figure 1 illustrates the program by semester and disciplinary area, including contact hours in theoretical lectures, practical classes, autonomous work, the credits (ECTS), assessment method and learning environment for each course.

The program has a total of 180 ECTS, distributed as follow: 60 ECTS in the area of Project, representing 33%, 38 ECTS (21%) in the area of Drawing and Communication, 30 ECTS (17%) in Mechanical Engineering, 16 ECTS (9%) in Materials. Mathematics, Industrial Design and Management and Innovation have 12 ECTS each (7%).

The student/teacher ratio varies according to the type of class (theoretical or practical) and the course's characteristics. Theoretical lectures (TL) have one teacher for the entire class that can go up to 45 students. For the practical classes, except for the project courses, the maximum number of students per class is 18, lectured by one teacher. The practical classes of the project courses have three to four teachers mentoring the students that are working in groups as will be explained in section 3. All the courses have a minimum of one additional tutorial hour per week for a more informal discussion and student guidance.

Recognition of the complex nature of the courses typology, has led to an understanding that courses can be ranked along a learning environment spectrum. For our purposes, we define a four grade scale that goes from the mainly LBL to mainly PBL. In between these two points we consider two kinds of mixed approaches: prevalent LBL with same open ended assignments (LBL-P) and prevalent PBL with support of lectured classes (PBL-L). In the proposed spectrum (included in Figure 1), the left-hand side corresponds to LBL approach and right-hand side to the constructivist, PBL, learning environment. From this spectrum perspective, a qualitative analysis of the program courses shows that PBL learning environment is present in 5 courses, PBL-L in 7, LBL-P in 1, and LBL in 16. On an analysis based on % of ECTS per learning environment PBL represent 29%, PBL-L 20%, LBL-P 3% and LBL 48%.

For the majority of the courses the assessment practiced is a mix of formative and summative components (Mixed assessment). The final grade results from the formative assessment performed during the semester and the summative component, which is a final exam. There is a four weeks period, after the semester, specific for the exams, scheduled for the entire University. Three courses, Mechanics and Materials, Quality and

Control and Economic Analysis of Projects only have summative assessment, consisting in a final exam (Final assessment). The courses Models and Prototypes, Drawing I and II and Product Engineering have continuous assessment, where only the students that have failed or wish to improve the grade are allowed to request a final exam (Continuous assessment). Because of the specificities of the project courses, the assessment is exclusively formative, the students cannot opt for a final exam to complete the course or improve the grade (Continuous assessment).

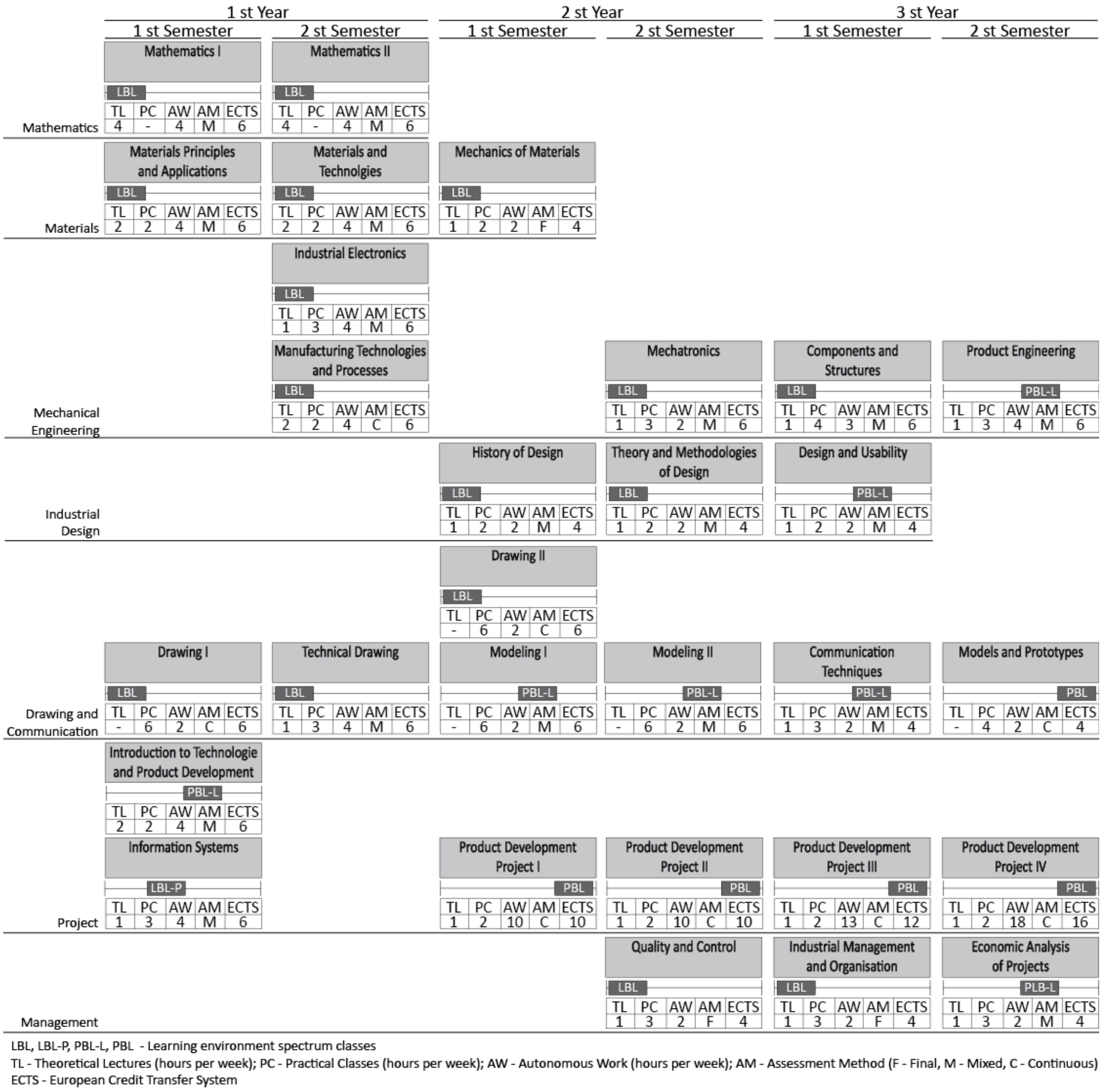

Figure 1. Technology and Product Design program architecture

Mixed assessment is present in eighteen courses representing, on an ECTS base, 54% of the program assessment, in this perspective final assessment, present in three courses, totalizes 7%, and continuous assessment, present in eight courses, represents 39%. Note that LBL courses are concentrated in the first four semesters.

RESEARCH METHOD

In order to obtain the students' perceptions about the presence of constructivist practices and principles in their learning environments, the questionnaire developed by Tenenbaum et al. (2001) was implemented. Three groups of students were selected for this study, one from Quality and Control course, which uses a traditional LBL approach and the other two using a PBL learning environment, from PDP II and PDP IV courses. The total number of participants in this study was 79, 24 for Quality and Control course, 29 for PDP II course and 26 for PDP IV course. The three groups are considered independents.

Product development project courses

The main objective of the Product Development Project (PDP) courses is to develop skills in new product development projects, interpreting, in an integrated way, markets' needs, as well as industrial, societal and environmental interests. Encourage project practice, create research habits for product development problem solving, and stimulate entrepreneurship are also included in the course objectives.

The project courses are based on a semester (14 weeks) with 1 hour per week for theoretical lectures, 2 hours per week for practical classes, and 1 hour per week for tutorial work. Based on differences in ECTS, described above, the students have to perform a weekly autonomous work of 10 hours in PDP I and II, 13 hours in PDP III, and 18 hours in PDP IV.

Theoretical lectures are reserved for discussion and content exposure applied to projects under development, taking over, with another deep, some knowledge gained during previous courses and applying it to the specific problem. The practical classes are dedicated to achieving a specific project, organizing to that end, students in small groups, which, through the practical implementation of a project to develop a new product, should be capable of: (i) integrating knowledge about the methodologies for product development, (ii) interpreting and incorporating the needs of the market in the new product, (iii) selecting materials, manufacturing processes, and technology, and (iv) developing and gaining dexterity at the use of management and representation product development process tools.

As there is no single way to solve a product problem, students are faced with the need to develop specific skills to solve it. This way, critical analysis and independent study, the demand for specific components and solutions and reasoned proposal for solutions to the problem proposed is encouraged through discussion and guidance of students' weekly work.

The process adopted for the product development courses is based on the Stage&Gate methodology (Cooper, 2001), with clear established milestones and fixed delivery dates (see Figure 2). At the end of each week the students must deliver the specific part of the problem solution as a document. This document is reviewed by the teachers and a weekly traffic light classification is applied. At the beginning of the following week, students are given formative feedback on the reviewed document and guidance on next steps. These discussions take place on weekly basis based on a predefined rotational scheme between the allocated teachers. At the end of the semester, 3 weeks are given for students to finalize the project report and for the preparation of the oral presentation.

The scheme for the remaining PDP courses, namely PDP II, PDP III, and PDP IV, is very similar with main differences occurring on the start and end points, the type of product and group sizes.

From PDP II onwards, the start point is an open project brief in PDP II (represented by Stage 2 in Figure 2), issued by the teachers and that need to be completed by the group, and a closed project brief in PDP III and IV, issued by the associated companies, the project's clients.

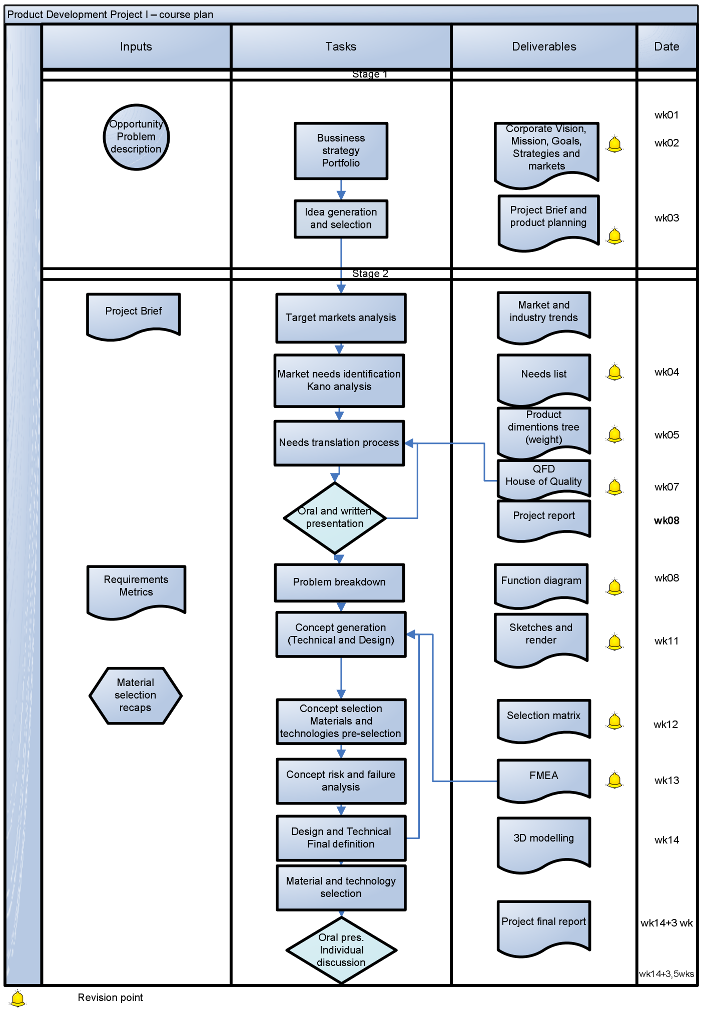

Figure 2. Product Development Project I course process (Ala, Gomes, & Torcato, 2011)

The end point for PDP II is a volumetric model of the product and the description of the design for manufacturing and the design for assembly. The end point for PDP III and PDP IV depends on the projects' complexity and goal(s).

Based on knowledge acquired during the semesters, the projects will vary from 100% mechanical products, ranging from shopping cart to cookware in PDP I, to electronic products in PDP II, ranging from a coffee machine to an indoor cycling energy generator, to a mix of projects in PDP III and PDP IV according to the partners' needs (local companies).

As stated before, the students are grouped in small teams, ranging from 4 in PDP I, to 3 in PDP II, to individual work in the remaining project courses. Initially the students are "guided" by teaching staff and in the third year the students work on individual projects for local companies and are "advised" by teaching staff. Because in PDP III and PDP IV students are working for a real client, the final assessment includes the criterion: *contribution to client's needs*; being this criterion qualified by the client.
The following criteria are used for assessment: (i) Middle semester oral and written presentation; (ii) Continuous development; (iii) Final product and report; (iv) Oral presentation; (v) Partners assessment. The last only applies to PDP IV courses and to the students that are integrated in companies to develop their projects. For a more detailed analysis of these courses refer to Ala et al. (2011).
Figure 3 shows an example of PDP IV step-by-step process accomplishments.

Figure 3. Product Development Project IV project example

Quality and control

This course focuses on the principles, practices and techniques of Total Quality and how these are reflected in the quality of products. Thus, complements prior learning (particularly in courses related to the process of product development) and contributes to the development of important skills to incorporate the concepts of quality in the student's future professional life.
The objectives of the course are: (i) the analysis of quality assurance and management systems in the development of new or improved products; (ii) application of tools to support the statistical process control to develop new or improved products. The student should leave the course capable of identifying different theoretical concepts of quality, knowing the ISO9000 standards, knowing and applying the main tools of quality

management and its statistical control and assuming continuous improvement as part of organizational development.
The teaching methods are based on a bipolar approach, being presented: (i) on one hand, methodologies, models and instruments for the management and control of quality and the identification and resolution of potential problems during the specific stages of the process of developing new products; (ii) on the other hand, based on literature review, case studies analysis and practical exercises, the students will be asked to reflect on the contents lectured by the teachers. The former is mainly performed during the theoretical lectures based on 1 hour per week for the entire class and the latter during the practical classes where the students are divided in two classes having 3 hours per week each.
The course uses summative assessment based on a final written exam in the examination period.
The learning environment of this course is clearly a lecture-based one as the students learn by listening, reading and practicing with exercises.

Instrument and Procedure

The students completed the questionnaire developed by Tenenbaum et al. (2001). The original questionnaire was translated into Portuguese by an educational scientist and then revised by the authors, to decide for the accuracy of translation and clearly phrased formulation. With the later it was done, by a specialist, retroversion to the original language, to confirm if the information and intention remains the same. In this process it was followed the procedure recommended by Eun-Seok et al. (2007).
To collect the three groups of data, the questionnaires were administered to all students who attended one of the classes near the end of their course, before knowing assessment results. Students were informed that their responses would remain anonymous and that participation was voluntary and confidential.
The validation of the original factor structure was done, with all the collected data, using Confirmatory Factor Analysis (CFA). The value for the Root Mean Square Error of Approximation (RMSEA = 0.08) indicates that the data set fits the 7-factor model fairly well (sufficient fit values are approximately 0.08) (Gijbels, et al., 2006) and the minimum discrepancy $\chi 2/df$ value (1.49) is smaller than 2.
The overall reliability of the translated questionnaire is high as indicated by the Cronbach´s α coefficient of 0.92. The α coefficients of the subscales: arguments, discussions, debates 0.76; conceptual conflicts and dilemmas 0.57; sharing ideas with others 0.74; materials and resources targeted toward solutions 0.73; reflections and concept investigation 0.81; meeting students' needs 0.77; and making meaning, real-life examples 0.71, are also all judged to be acceptable for assessing differences between groups.

RESULTS

The students' responses were analyzed for each PBL course, PDP II and PDP IV, *versus* LBL course, Quality and Control, by means of a one-way multivariate analysis of variance (MANOVA), followed by analyses of variances (ANOVA) using the Bonferroni method on each dependent variable. The effect size (d-index) was calculated for each factor in order to analyze the possible differences between each of the two PBL courses and the LBL course. For the interpretation of the d-index it was used de guidelines used

by Gijbels et al. (2006) that generally take as reference the following values for d modulus: |d|=0.2 as a small effect; |d|=0.5 as a moderate effect and; |d|=0.8 as a large effect.
A preliminary analysis was done to check the normality and homogeneity of the variance assumptions: Shapiro-Wilk test for normality and Levene's test for equality of variances. All assumptions for the analysis were met.
The results of the MANOVA for de courses PDP II/Quality and Control (Wilks's Λ=0.59, $F(7,45)=4.57$, $p<0.05$) and PDP IV/Quality and Control (Wilks's Λ=0.72, $F(7,42)= 2.32$, $p<0.05$) showed significant differences on the dependent measures. The multivariate η^2 based on Wilks's Λ was quite strong, 0.42 for the former and was not so strong, 0.28, for the later.
Table 1 presents means and standard deviations of the seven key components of constructivist learning environments in the three courses and calculated effect sizes. The results show that the difference between the mean values of the LBL course and the PBL courses goes in different directions depending on factor. In some factors there is even a negative effect size for PDP II and positive effect size for PDP IV, using as reference the LBL course Quality and Control.

Table 1. Means and Standard Deviations of the seven key components of constructivist learning environments in the three courses (d = effect size)

Dimensions	Quality and Control		PDP II			PDP IV		
	M	SD	M	SD	d	M	SD	d
F1. Arguments, discussions, debates	3,68	0,57	3,66	0,50	-0,05	4,02	0,59	0,57
F2. Conceptual conflicts and dilemmas	2,89	0,56	3,02	0,50	0,25	3,12	0,67	0,36
F3. Sharing ideas with others	3,79	0,71	3,55	0,65	-0,36	3,86	0,63	0,10
F4. Materials and resources targeted toward solutions	3,83	0,68	3,59	0,70	-0,36	3,69	0,68	-0,21
F5. Motivation toward reflections and concept investigation	3,49	0,64	3,72	0,54	0,40	3,87	0,62	0,60
F6. Meeting students' needs	3,27	0,82	3,17	0,57	-0,14	3,56	0,58	0,42
F7. Making meaning, real-life examples	3,97	0,56	3,40	0,64	-0,93	3,76	0,63	-0,35

PDP II/Quality and Control effect sizes tend to be negative revealing a less constructivist learning environment perception. Small effect size values, around |d|=0.2, are observed for the factor conceptual conflicts and dilemmas and in negative direction for the factors arguments, discussions, debates and meeting student needs. Larger values, around |d|=0.4, are encountered for the factor motivation toward reflections and concept investigation and in a different direction for the factors sharing ideas with others and materials and resources targeted toward solutions. The factor making meaning, real-life examples presents a large effect size value in a negative direction.
PDP IV/Quality and Control effect sizes tend to be positive, revealing a more constructivist learning environment perception by the students. In the negative way there are two factors, materials and resources targeted toward solutions with a small size effect and making meaning, real-life examples with a medium size effect. In the positive direction, small effect size values, around |d|=0.2, are observed for the factor sharing ideas with others. Larger values, around |d|=0.4, are encountered for the factors: arguments, discussions, debates; conceptual conflicts and dilemmas; motivation toward reflections and concept investigation and; meeting student needs. None of the factors of PDP IV/Quality and Control effect size analysis presents a large effect size value.

Using the Bonferroni method, each ANOVA was tested at the 0.007 level (0.05/7). The results of this analysis only showed significant differences between the PDP II and Quality and Control to the seventh factor (making meaning, real-life examples; $F(1,51)=4.12$, $p<0.007$, $\eta^2=0.18$). Note that, for larger samples with the same effect size values, it is expected that more factors present significant differences.

DISCUSSION

When considering the overall structure of the program and courses' architecture and scope, we verify that although project-based learning is significant, the majority of the courses, 48% of the ECTS, are lecture-based. Courses belonging to the areas Drawing and Communication and Project have, in their roots a project-based learning approach, whereas the majority of the remaining courses are thus far more "traditional" in the sense that they are content driven, subject oriented.

Based on our experience, we can state that project-based courses imply a greater workload for both teachers and students. For example, the work process shown in Figure 2 means that the students cannot postpone their work. In fact, the project is ongoing in the sense that students must reflect on the feedback given to improve the work they have carried out, and also as a guide for the work to develop in the week to come.

Teachers have timeframes to provide continuous formative feedback. The traffic lights system requires for all teachers to work collaboratively in order to assess the students' work. Teachers meet weekly to discuss the work carried out by students and determine the appropriate feedback for students to be able to improve their projects. Furthermore, in each practical session there are several teachers (usually PDP I and II have an average of 4 teachers, and PDP III and IV have an average of 3 teachers) that provide individual group support. The teachers come from different backgrounds constituting a multidisciplinary team including industrial designers, mechanical and industrial engineers, and materials and electronic specialists. They have to engage with students and answer questions pertaining to different areas of product development. Teachers have to be open to dialogue, discussion and negotiation, as different opinions may confuse students. From our experience we can say that, especially in the first project, students often are not able to acknowledge the added value of different constructive opinions and focus on the opinion of one teacher.

On the other hand, "traditional" lecture-based courses often imply a higher student-teacher ratio. Teacher focuses on the specific content for his/her class, and assessment is based on exams. Students must only follow the classes and study for the exams. It is our perception that for many students, this more "traditional" approach is highly embraced as it implies less work. However, less work normally results in poorer performance. This may be a reason for the high number of dropouts verified in Quality and Control course, presented in Table 2.

Triangulation of the students' perceptions and assessment results do not support previous research findings. This research revealed that the students do not perceive a significant difference between learning environments that are clearly of different nature, which goes against the findings of Gijbels et al. (2006). However the learning environment clearly influences the students' learning results, as depicted in Table 2. A more constructivist learning environment positively affects the success rate of the course, even considering that the students do not perceive the difference.

Several reasons may contribute for this: (i) Although Quality and Control is LBL it applies the "Bologna Process" practices, namely instilling reflection by case studies analysis and exercises. This is confirmed by the highest (M=3.97) score obtained in the factor making meaning, real-life examples. (ii) The greatest difference in perception was measured in the factor motivation toward reflections and concept investigation (|d|=0.4 for PDP II and |d|=0.6 for PDP IV), that can be considered to have a moderate effect. Thus, this is the only factor with clear agreement with the real constructivist presence in the courses. Possibly, for the engineering design discipline and/or for this particular program, the key dimension of constructivist learning environments is the motivation toward reflections and concept investigation. Or students did not properly understand the intended meaning of the questions related with the other factors. (iii) As the questionnaire was submitted to the students near the end of the semester, most of the students of Quality and Control that failed were not at the class. Thus, the majority of the students that filled the questionnaire had positive learning results. It is no surprise that these students have a good perception about the constructivist features of the course.

Table 2. Assessment results in the three courses

Assessment	Quality and Control		PDP II		PDP IV	
	n	%	n	%	n	%
Approved	31	56%	33	89%	27	93%
Failed	3	5%	3	8%	0	0%
Dropouts	21	38%	1	3%	2	7%
Total	55	100%	37	100%	29	100%

We cannot neglect, however the high success rate of the Product Development Project courses (see Table 2). Although we admit that greater demands are placed on students, the results suggest good levels of student engagement and interest. Thus, we question if the project-based learning approach should be implemented in other courses, namely those where student success rate is still lacking. These courses tend to be content driven courses, and as such we should reflect if it is wise to implement this approach. Comparing the dropouts of Quality and Control (38%) with the PBL courses (3% and 7%), we argue that students are more persistent and stay in the course till the end in the PBL courses.

According to the data there is no evidence of a direct relation between the constructivist learning environment perception and the teaching/learning model adopted. It seems that the students' perception is related with the content of the courses. The specific project theme proposed by the teachers of PDP II in the semester of the study was somewhat distant from students' reality.

CONCLUSIONS

In this study it was developed a framework for the presentation of a multidisciplinary undergraduate program allowing a more holistic view of the curriculum, learning environments and disciplines involved. A learning environment spectrum was developed for the classification of the courses.

Some results of the questionnaire were inconclusive, not supporting the conclusions of previous studies that argue the constructivist nature of PBL. Among the seven factors of constructivist learning environments, the students only perceived a moderate difference in the factor motivation toward reflections and concept investigation.

Despite the high overall reliability of the translated questionnaire, we should consider the possibility that the students did not properly understand the intended meaning of the questions.

In conclusion both the learning environments and the contents of the courses contribute to the students' perceptions. Constructivism could be reached balancing the LBL and PBL approaches depending on the contents and pedagogical goals of each course. Further work is needed in order to find the factors that determine the equilibrium for each course along a spectrum similar to the one proposed in this paper. If we expand project-based learning to other courses will we be able to reduce the dropouts and improve the overall productivity of the program? Implementing an inductive teaching and learning approach based on the constructivism model/philosophy requires a cyclical process of implementation and evaluation, which is a very demanding task for faculty.

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