# PRODUCT DEVELOPMENT PROJECT COURSES IN AN ENGINEERING DESIGN DEGREE PROGRAM

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**ABSTRACT**
The main objective of this paper is to briefly characterize the first cycle degree program *Technology and Product Design* offered by University of Aveiro and present the project courses of this interdisciplinary curriculum in order to contribute to the discussion about engineering design education pedagogy. The four project courses, based on a project-based learning model, are described and analyzed, supported on courses specific characteristics, structure, outputs, group sizes and pedagogical practices. Moreover, to verify the contribution of project-based learning to the success of the project courses, assessment criteria and approval rates are discussed.

*Keywords: Engineering design education, project-based learning, project courses*

## 1 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 industry. Among other efforts, a new polytechnic school, the *Higher School of Design, Management and Production Technologies of Aveiro North*, was established in 2004, with a new first cycle degree program *Technology and Product Design* offered as of 2005/2006 academic year.

The above-mentioned program is in 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.

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. It then describes the program structure with emphasis on the project courses that constitute the backbone of this interdisciplinary curriculum. These courses are based on full-semester product development projects where students learn through practice and integrate the knowledge acquired in subject-oriented courses.

## 2 TEACHING/LEARNING MODELS IN ENGINEERING EDUCATION

In recent years European Higher Education Institutions have put a big effort on implementing a student-centred learning model, which is one of the most important (and most 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. 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 [1]. 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 students in the traditional engineering programs. To overcome these limitations a significant change in the current philosophy and structure of engineering education is required.

Barrows [2] describes 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 [3] states 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". 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 where self-directed learning is crucial.

Literature has shown that in engineering education, project-based learning (often referred to as project work [4]) is more adequate as it "more closely mirrors the professional behaviours of an engineer" [1]. 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 [1, 4] 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.

## 3 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.

This degree constitutes a unique educational offer in Portugal, oriented towards the innovation, drafting, development and optimisation of products and processes. It favours the preparation of professionals with an interdisciplinary, largely technical profile, combining industrial design with mechanical engineering to offer skilled professionals able to participate in all product development phases. In order to accomplish this, the study plan is based on several areas like mathematics, materials, mechanical engineering, industrial design, drawing and communication, project, management and innovation. Figure 1 illustrates the program by semester, including contact hours in theoretical lectures, practical classes, autonomous work and the credits (ECTS) for each course.

The student/teacher ratio varies according to the type of class (theoretical or practical) and the course's characteristics. Theoretical lectures 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 5. All the courses have a minimum of one additional tutorial hour per week for discussion and student guidance.

There are courses that only have summative assessment, consisting in a final exam, being the majority of them assessed by a mix of formative and summative components. The final grade results from the formative assessment performed during the semester and the summative component (final exam).

## 4 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, technological developments and industrial, societal and environmental interests. Included in the courses objectives is the encouragement of project practice, creation of research habits for problem solving, and stimulation of entrepreneurship.

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, per project course (see Figure 1), the students have to carry out weekly autonomous work of at least 10 hours in PDP I and II, 13 hours in PDP III, and 18 hours in PDP IV.

Theoretical lectures are reserved for content exposure and deep discussion of knowledge from previous courses, and then applying it to the specific problem. The practical classes are dedicated to develop a new product, where students are organized in small groups. By the end of the courses they 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.

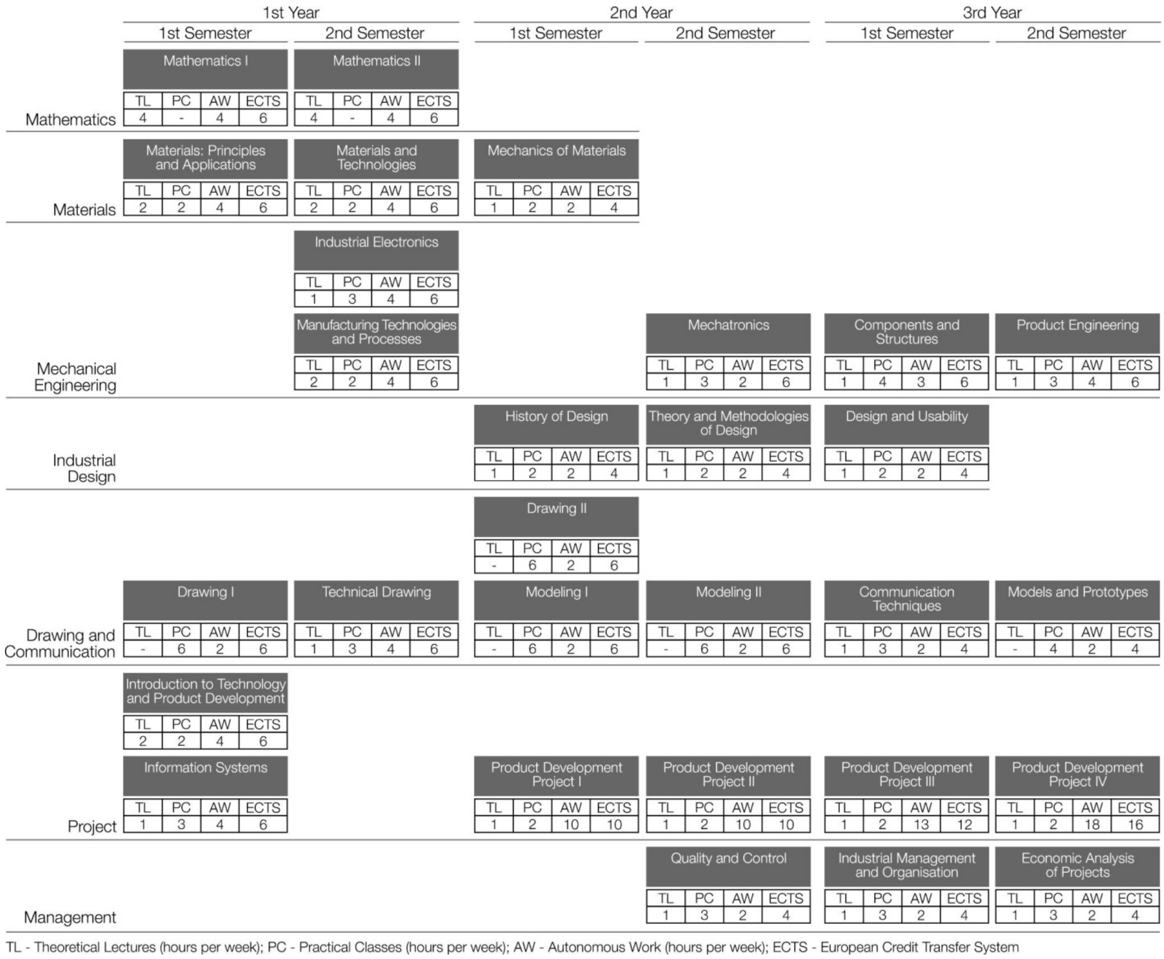


*Figure 1. Technology and Product Design program architecture*

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 [5], with clear established milestones and fixed delivery dates (see Figure 2).

The PDP I course is based on a weekly workload project process (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.

On the first day of the PDP I course, the students are faced with the description of the problem, based on a opportunity identification. Based on that, and to promote contact with the industrial reality and constrains, they have to create a fictitious company with its specific mission, vision, strategic goals and markets, as well as the available and future technologies and portfolio.

For the idea generation and selection, students have to identify, select and apply one of the management tools that they had study in previous courses and, at the end, they have to issue the product project brief. At this point the groups will have different ways to solve the problem as they have different companies, and different objectives, markets and constrains for the product. After a market and industry trend analysis, they have to identify and select the best tool and methodology to identify the market's needs and the technical way to respond to those needs. During week 8, middle of the semester, the first milestone takes place. The inputs for it are a project report and an oral presentation and discussion on the work done so far.

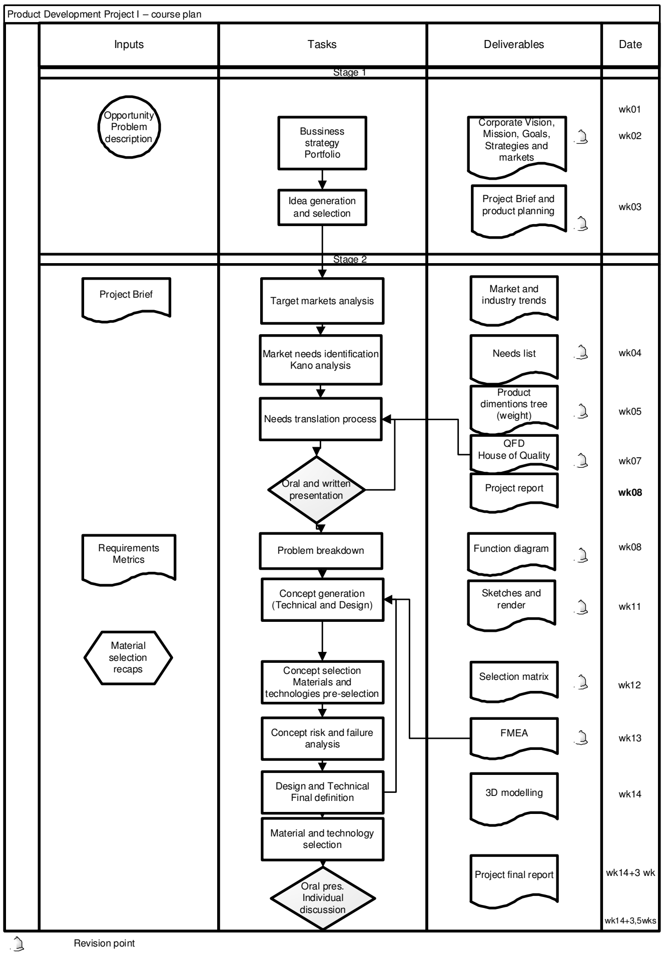


*Figure 2. Product Development Project I course process*

Based on the formative feedback given by the teachers for this milestone, students begin the activity of concept generation, which means creating a concept gallery of sketches and freehand renders each one with a pre-selection of materials and technologies. Here, once again, the students have to identify multiple concept sources and techniques.

Based on a concept screening and a concept scoring matrix, the final concept is selected by the group on which they have to apply the Failure Mode and Effect Analysis (FMEA) and adapt it accordingly by building a 3D CAD model with the final technical and aesthetical definitions, and the selection of materials and technology.

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 (10 minutes duration). Table 1 describes the criteria and marks used for assessment in each project course.

*Table 1. Criteria and marks used for assessment per project course*

| Assessment Criteria | PDP I | PDP II | PDP III | PDP IV |
|---|---|---|---|---|
| 1.$^{st}$ oral and written presentation | 20% | 15% | 10% | - |
| Continuous development | 20% | 75% | 70% | 50% |
| Final product and report | 40% | | | |
| Partners' assessment | - | - | 20% | 30% |
| Final oral presentation | 20% | 10% | | 20% |

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. The start point is an open project brief in PDP II (represented by Stage 2 in Figure 2), issued by the teachers,

which needs to be completed by the group, and a closed project brief in PDP III, issued by *School* partners. In PDP IV the students are integrated in companies where they have to develop their project(s). 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 in PDP I, to electronic products in PDP II, to a mix of projects in PDP III and PDP IV according to the partners' proposals (local companies), as shown in Table 2.

*Table 2. Projects developed in each course*

| | PDP I | PDP II | PDP III | PDP IV* |
|---|---|---|---|---|
| 2006/2007 | Flexible exhibition stand system | Coffee machine | | |
| 2007/2008 | Sitting artefact | Grill broiler | Urban furniture; Terrace furniture | Train and automotive seats; Machinery housing |
| 2008/2009 | Design for flexibility product based | Design of dedicated CFL fixtures | Bathroom equipment; Bicycle accessories; Domestic appliances | Taps and handles; Plastic automotive components |
| 2009/2010 | Shopping cart | Indoor cycling energy generator | Urban furniture; Bathroom furniture; Heat pumps and water heaters components | Computer cases; Urban furniture |
| 2010/2011 | Cookware | Multifunctional toaster | Heat pumps, control valves, bicycle components; Lightening equipment | Solar panel casing; TV remote controls |

* Examples of product development projects on 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. The level of complexity and student autonomy increases over the years. Initially the students are guided by teaching staff and in the third year the students work on individual projects for or, in PDP IV, on local companies and are advised by teaching staff. Figure 3 shows an example of PDP IV step-by-step process accomplishments.

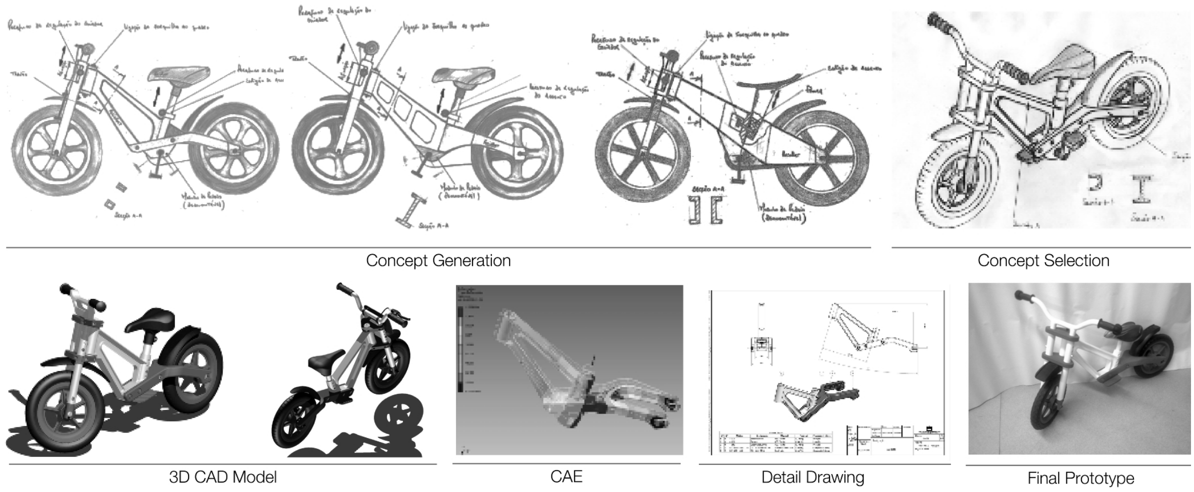


*Figure 3. Product Development Project IV project example*

## 5 DISCUSSION

Based on this experience, it can be stated that project-based courses imply a greater workload for both teachers and students. For example, the work process showed 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 serves 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, used in PDP I, or the weekly review applied in remain project courses, 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. 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. These 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. 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.

The high success rate of the PDP courses is noticeable (see Table 3). Although greater demands are placed on students, the results suggest good levels of student engagement and interest. Thus, it can be questioned if the project-based learning approach should be implemented in other courses, namely those where student success rate is still lacking.

*Table 3. Students enrolled and approved in Product Development Project courses*

| | 2006/2007 | | 2007/2008 | | 2008/2009 | | 2009/2010 | | 2010/2011 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Enrolled | Approved | Enrolled | Approved | Enrolled | Approved | Enrolled | Approved | Enrolled | Approved |
| **PDP I** | 20 | 80,0% | 25 | 80,0% | 37 | 89,2% | 30 | 70,0% | 39 | 64,1% |
| **PDP II** | 24 | 66,7% | 20 | 100,0% | 30 | 93,3% | 26 | 73,1% | | |
| **PDP III** | | | 13 | 92,3% | 18 | 77,8% | 34 | 64,7% | 32 | 78,1% |
| **PDP IV** | | | 16 | 87,5% | 17 | 76,5% | 30 | 63,3% | | |
| **Total** | 44 | 73,3% | 74 | 89,2% | 102 | 86,3% | 120 | 67,5% | 71 | 70,4% |

However, the approval rate is generally decreasing in the last three academic years, which is a motive of concern. Although in 2009/2010 all the project courses had a decrease in their approval rate, the data collected for the current academic year (first semester courses) does not reinforce this general negative tendency. In fact, there is a slight inversion of the trend. Based on this data it can be stated that the minimum approval rate for the PDP courses is 63% and the average is tending to 77%. It is worth notice that in this degree program, the average approval rate of content driven courses that are based on summative assessment is 35%. PDP I has the minor standard deviation in the approval rate and PDP II has the major standard deviation, probably a consequence of the complexity of the products electronic systems. The approval rate of PDP III and PDP IV decreased in the first three years because of the autonomous workload needed and most likely because weaker students, who were retained due to difficulties in the previous courses, have progressively enrolled.

## 6 CONCLUSIONS

Being the average approval rate for all the editions of the project courses 77%, it can be concluded that the project-based approach leads to better results when compared with the traditional lecture-based approach, which have 35% approval rate. However, further work is required in order to better understand the causes for student retention and develop actions to verify the relation between PDP courses approval rate and the following parameters: (i)approval rate in the first year courses, namely the ones that are relevant for PDP courses; (ii)student autonomous and group work capacity, namely working students; (iii)student capacity for planning and managing their own time, namely in PDP III and PDP IV. Another topic for further work is to understand the impact of PBL methodology in acquired knowledge and skills using short or long term projects.

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