Assessing International Product Design And Development Graduate Courses: The MIT-Portugal Program

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ABSTRACT

The Product Design and Development (PDD) course is part of the graduate curriculum in the Engineering Design and Advanced Manufacturing (EDAM) study in the MIT-Portugal Program. The research participants included about 110 students from MIT, EDAM, and two universities in Portugal, Instituto Superior Técnico—Universidade Técnica de Lisboa (IST) and the Universidade do Porto (FEUP). We investigated the PDD EDAM course in the context of the two other groups who studied a similar course in a different setting. Research tools included questionnaires, with questions related to students' learning outcomes and perceptions as well as focus groups with EDAM faculty and students. We assessed the EDAM course format of several concentrated two-week long periods compared with a regular semester based on students and faculty feedback. In a question related to the product life cycle stages the MIT and EDAM students listed on average a higher number of items than that of the IST and FEUP students, indicating a higher level of learning. The learning approach that follows the MIT PDD course has been instrumental in successfully incorporating hands-on activities and student-faculty interactions into the EDAM program.

Keywords: product design, assessment, international education

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INTRODUCTION

Engineering is under constant change due to increasing globalization, impacting the way engineers work and companies make use of their employees' innovation. As Vest [1] noted:

"The engineering workforce of tomorrow, and indeed that of today, will face profound new challenges. Every day the men and women of this workforce will face the stress of competing in the fast-paced world of change we call the knowledge-based global economy of the twenty-first century. They will also face even larger challenges because the nation and world will need to call on them to seize opportunities and solve global problems of unprecedented scope and scale." (p. 235)

This is the context in which the MIT-Portugal Program (MPP) has been formed as an initiative by the Portuguese Government. MPP, which includes six Portuguese Universities and the Massachusetts Institute of Technology, was created after recognizing that Portugal was lagging behind in the world economy for the past decade or more. MPP, together with programs with other foreign universities, was initiated with the objective of enhancing Portuguese higher education and bringing it closer to industrial needs [2]. MPP is divided into four different focus areas: Biotechnology, Sustainable Energy Systems, Transportation Systems, and Engineering Design and Advanced Manufacturing (EDAM). Within the EDAM focus area, three Portuguese engineering schools are involved: Escola de Engenharia da Universidade do Minho (UM) in Guimarães, Faculdade de Engenharia da Universidade do Porto (FEUP) in Porto, and Instituto Superior Técnico (IST)—Universidade Técnica de Lisboa in Lisbon.

The main objective of the Engineering Design and Advanced Manufacturing (EDAM) focus area is to provide Portuguese industry with people with higher education levels and global perspectives on engineering design and product development—the core capabilities in technological innovation. EDAM itself is divided in two separate third cycle study programs: the doctoral program in Leaders for Technical Industries (LTI) and an Executive Masters program in Technology Management Enterprise (TME). The set of courses devised to fulfill the objectives for these programs is explained elsewhere [2].

One of the key courses offered to both LTI and TME students is the Product Design and Development (PDD) course. This course was developed based on project-based learning, as a means to introduce students to the challenges commonly confronted within the engineering profession. The engineering profession involves handling uncertainty, incomplete data, constant change in the working environment, and conflicting requirements from various stakeholders. Despite the superiority

of project-based learning for addressing these challenges, lecture-based delivery is still common practice in many universities and colleges [3].

Project-based or Problem-based Learning in Higher Education

Project-based or problem-based learning (PBL) has been defined in the educational literature rather broadly. PBL has been used interchangeably for problem- and project-based learning. Thomas [4] who reviewed research on PBL found five criteria for classifying this approach:

1. Centrality: PBL-type projects are central to the curriculum.
2. Driving question: The projects focus on questions or problems that "drive" students to confront central concepts and principles of a discipline.
3. Constructive investigations: The central activities of the project involve students' knowledge construction.
4. Autonomy: Projects are student-driven to a significant extent.
5. Realism: Projects are realistic or authentic.

With the strong encouragement of the ABET engineering accreditation criteria, upper level engineering courses have evolved over the years from projects "invented" by faculty to industry-related projects where companies provide authentic problems, along with expertise and sometimes financial support [5, 6]. Examples of studies that investigate the effect of PBL in higher education included cooperative undergraduate student projects [7], science projects carried out by prospective teachers who acted as practitioners and as instructors [8], and a research conducted at the Technion, Israel Institute of Technology, which integrated project-based learning into three academic chemistry courses [9]. In the latter study, undergraduate science and engineering students who carried out PBL activities performed significantly better than their control peers not only on their posttest, but also on their course final examination. The results indicated that PBL incorporated into academic courses can enhance students' understanding of chemical concepts, theories, and molecular structures.

PBL in Engineering Courses

Developments in student-centered approaches, such as project-based learning, are just starting to make a dent in the practice of engineering education [10, 11]. There is a gap between Portuguese universities and industry with respect to product development and entrepreneurship. Teaching these topics is expected to promote students' thinking skills and ability to successfully launch new businesses [12]. Particularly at senior levels of engineering degree programs, others are also experimenting with project-based learning. The differences between freshmen and seniors in design problem solving are another important topic of research. Researchers performed a comprehensive study to analyze the behavior of freshmen and senior students when faced with

a typical open-ended design problem. Results have shown that seniors produced higher quality solutions, spent more time solving the problem, considered more alternative solutions and made more transitions between design steps than freshmen [13, 14]. Given the results from this study, one can infer that the difference between freshmen and seniors is the capacity of the latter to concentrate not only on solving the problem but also on setting the problem itself [15]. This is an extremely important fact, often seen in freshmen's work method: concentrating on problem solving, relying on rational and cognitive tools and deductive procedures. Design problems are oftentimes ill-defined and always encompass non-technical issues. This renders deductive and rational approaches inadequate before the actual problem is well set and a reasonable design boundary is drawn.

There are a number of universities that have excelled over the years in teaching product development to their undergraduate and graduate students, one of which is undoubtedly MIT. Product development encompasses activities that are part of the product lifecycle, starting with a market need and ending in the production and sale of the product. According to Ulrich and Eppinger [16] the product development process is the sequence of activities carried out by an enterprise to design, build, and commercialize a product. The PBL approach to teaching lends itself to the broader perspective that is needed for today's engineers, who must be capable of crossing boundaries to understand technical and non-technical issues in design problems and collaborate with peers from a variety of disciplines.

RESEARCH GOAL, QUESTIONS, AND SETTING

The goal of this research was to assess the Product Design and Development (PDD) course primarily within the EDAM focus area of the MIT-Portugal Program. The research included graduate students who were divided into three groups: (1) Engineering Systems Division at MIT, (2) EDAM program, which included students from three universities in Portugal, and (3) Instituto Superior Técnico – Universidade Técnica de Lisboa (IST) and Faculdade de Engenharia da Universidade do Porto (FEUP). The EDAM course is a Ph.D. level course – or, in the European jargon, at a third cycle level – whereas the others are all at a Masters level. The research questions called for (1) assessing the PDD EDAM course and (2) finding similarities and differences between the three groups who studied the PDD course.

Condensed Teaching Weeks Versus Semester-Long Traditional Courses

As noted by the National Academy of Engineering [17], to maintain economic competitiveness and improve the quality of life for people around the world, engineering educators and curriculum

developers need to "anticipate dramatic changes in engineering practice and adapt their programs accordingly." Along these lines, one of the topics of most interest was the effect of the particular method of teaching within the MIT-Portugal Program. The courses are taught simultaneously to students from the three Portuguese universities in a co-located way because this is superior for PBL than video-based teaching[1]. Since the universities the students attend are distributed across Portugal, the courses in this program are taught in two condensed periods of one week classes, separated by six weeks without classes. A second reason for the condensed week approach was to involve students in the TME program that would retain their job during the program. In the beginning, this structure was considered potentially disruptive. However, it does reflect current product development practice, which in many cases is conducted on a globalized basis, in which development teams are dispersed around the world [18]. The geographical distribution of the team provided us with a realistic environment useful for PBL and a way of assessing whether this way of developing products has significant implications on the quality of the products, the teamwork and/or the teaching and learning experience.

The Product Design and Development Courses

All three PDD courses used the textbook "Product Design and Development" [16] as a foundational resource, but some extra readings were sometimes proposed for some specific topics (see Table 1).

The MIT graduate students studied a project-based semester-long PDD course.

Within the EDAM curriculum, the PDD course is part of the Ph.D. and Advanced Study programs. The EDAM PDD course focuses on teamwork, integration of interdisciplinary domain knowledge, with emphasis on system thinking in an industrial setting [19]. The EDAM course was taught by Portuguese faculty from IST, FEUP, and UM, in collaboration with MIT faculty in a condensed schedule with emphasis on project-based learning. This program has a condensed structure. It starts with one-week of intensive lectures, followed by six weeks without lectures. This structure repeats and ends with students' presentations. During their two six-week periods without classes, students have to turn in nine assignments designed to guide them through the product development process, which is adapted to their specific project. Instructors then comment on these assignments individually. Each professor sends his comments independently of the others. This process helps the student teams improve their projects towards the final presentation. After the second six-week period, the students convene for presentations of their projects, in which they also have to show a working prototype and hand in a full report.

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[1]The courses are taught by a team of MIT faculty and Portuguese faculty from the three Universities involved.

PDD Course details	Product Design & Development graduate course at MIT	Product Design & Development graduate course at EDAM	Product Development graduate course at IST	Methods of Product Development graduate course at FEUP
Textbook	Ulrich & Eppinger's Product Design and Development; but not relied on heavily because students have used it in a previous class	Ulrich & Eppinger's Product Design and Development; other selected readings	Ulrich & Eppinger's Product Design and Development	Ulrich & Eppinger's Product Design and Development; Christensen, The Innovator's Dilemma
Teaching Method	Project-based learning in collaboration with guest lecturers from industry	Project-based learning in a condensed two weeks format with collaboration of faculty from three Portuguese universities & MIT	Mostly traditional	Traditional
Scope of course content	Basically all chapters of Ulrich & Eppinger's book, but lectures do not follow the book; instead most classes are given by expert guest lecturers and a deeper intellectual approach is taken, emphasizing system issues	Almost all of Ulrich & Eppinger's book, although some topics are taught with other readings as a basis	Almost all of Ulrich & Eppinger's book	Product Design Methods, with relevance to physical products
Main message to the students	Need to understand all the steps, keep customer needs as primary goal at all times. Emphasis on system issues in design and management	Need to understand all the steps, keep customer needs as primary goal at all times. Emphasis on system issues in design and management	Need to understand all the steps, keep customer needs as primary goal at all times. Emphasis on system issues in design and management	Study and become familiar with the use of different tools and techniques to develop systematically and methodically innovative products, carefully considering the role to be played by the various functional areas of the company
Scope of project if any	Full product development process, from idea to a working prototype, including business plan	Full product development process, from idea to a working prototype, including business plan	Full process development process, from idea to a working prototype, including business plan	Concept development project: identify needs, produce a specification, select concept
Faculty back-ground	Engineering and business with many expert guest lecturers	Mainly Engineering	Mechanical Engineering and some training from MIT's Sloan School	Mechanical Engineering and training in product development at Sloan School

Table 1. Comparison of the MIT, the EDAM, and the IST and FEUP PDD courses.

PDD Course details	Product Design & Development graduate course at MIT	Product Design & Development graduate course at EDAM	Product Development graduate course at IST	Methods of Product Development graduate course at FEUP
Students background	Engineers and engineering managers with 5-10 years work experience, many in software; working at companies while taking the class; lack of industrial designer (ID) students, which was compensated for by receiving help from professional ID advisors	Engineers and engineering managers with varying work experience, working at companies while taking the class and fresh graduate students from several engineering areas	Graduate students from Industrial Management, Mechanical Engineering, and Aerospace Engineering	Engineers, mainly mechanical engineers, designers, and architects
Business content in syllabus	Similar to text plus reading of important scholarly papers with emphasis on strategic issues	Similar to text, plus some cost models built in a different concurrent course	Similar to text	Organization of a product/service development process in the enterprise
Project team size	Initially 3-4, growing to 6-7 after about half the ideas are eliminated mid-way through the course by a vote of the students	5-6 students. Each team must have Leaders for Technical Industries (LTI) and Technology Management Enterprise (TME) students	3 to 4 students, if possible with different backgrounds	Up to 5 students, with different backgrounds when possible
Origin of project topics	From students who form groups first, then select a group project idea	From the teams of students	Students' ideas subject to faculty approval	Ideas proposed by students or faculty
Reports, Presentations	Six reports, one short mid-term presentation, one longer final presentation	Eight reports, one mid-term presentation, one final presentation and final report	Six reports, one final presentation	Two presentations of case studies, one final report
Project budget	$1000	1000€	None, but students are encouraged to search for sponsors	No budget available
Other facilities needed	Whatever the students can find, usually at their companies	Machine shops available at universities, plus whatever students can find	A machine shop available at IST to build soft prototypes and mock-ups	No prototypes are developed in the project
Emphasis on patents	Not pushed too hard, but occasionally a good idea is patented. Students must make a competitive analysis in their first report: other similar products, patents granted on similar ideas	Students must make a competitive analysis in their first report and further downstream: other similar products, patents already granted on similar ideas	Highly recommended and valued, with a significant number of patents filed (50 so far). A guest seminar is usually given by a patent specialist.	Not relevant so far
Faculty mentoring	Engineering faculty and industrial design professionals	Engineering faculty	Engineering faculty	Engineering faculty and invited guest occasionally

Table 1. continued...

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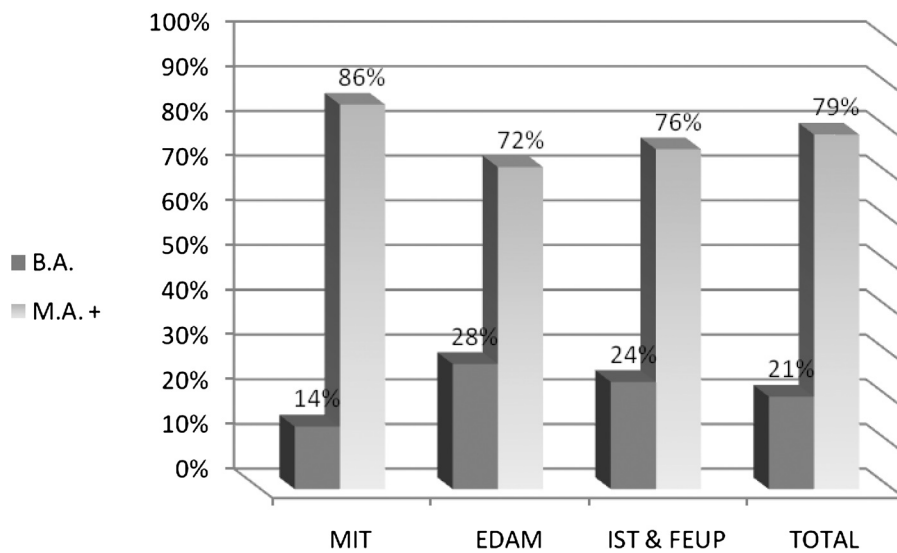| Area of Expertise	N	Percent
Engineering	75	60%
Management	66	52%
Manufacturing	51	41%
Industrial Design	36	29%
Other	28	22%

Table 2. Students' areas of expertise.

Figure 1. Graduate students' distribution by their prior academic degree.

The third research group—IST and FEUP—took two separate, more traditional, semester-long PDD courses. These two groups were combined because their pedagogical approaches were similar. Table 1 shows a comparison of all the courses studied.

The Research Participants

About ten EDAM faculty and 116 graduate students participated in this study. The students who re-sponded to the pre-questionnaire consisted of 50 MIT, 25 EDAM, and 41 IST & FEUP students. Figure 1 describes the distribution of these students by their prior academic degrees: B.A. and M.A. or higher.

Comparing the students' distribution by prior academic degrees using Pearson Chi-Square, no significant differences were found between the three research groups. The students were asked to specify their area(s) of expertise and number of experience years in each of those areas. Many students indicated more than a single area of expertise.

Table 2 lists the students' number and percentage of the entire population by their declared areas of expertise. The percentage sum exceeds 100% as students were able to specify more than one area of expertise. The distribution shows that engineering is the most prevalent expertise, followed by management and manufacturing.

Using Pearson Chi-Square, no significant differences were found between the three research groups with respect to distribution of work experience in any one of the areas, except for engineering. Figure 2 presents the distribution of engineering work experience, showing that the vast majority of MIT graduate students have three or more years of engineering experience, while most of the Portuguese graduate students (EDAM and IST & FEUP), have less than three years. This difference was significant ($\chi^2 = 25.74$, $p < 0.0001$).

Since the only difference found between graduate MIT and Portuguese students was the engineering work experience, we revisited the distribution of academic degrees. Examining MIT and Portuguese students with respect to their Master degree in engineering, we found a significant difference ($\chi^2 = 20.87$, $p < 0.005$). There were significantly more MIT students holding a master degree in engineering (80%) than their peers: 40% in EDAM, and 61% in IST & FEUP.

The Research Tools

Research tools included (1) pre- and post-questionnaires, administered to the students of all three research groups, (2) focus groups for EDAM faculty and students, and (3) end-of-semester perception questionnaire. We focus on the analysis of several questions related to students' understanding and perceptions. Questions included describing key PDD concepts and processes, ranking reasons for product success, and identifying team and individual skills required for working on a product development project. In the open-ended questions, students' responses from all three groups were analyzed and the extracted items were grouped into categories. These categories were primarily based on the courses textbook [16] with refinement based on items gleaned from the text written by the students.

Methodology

The study has employed the qualitative approach in the analysis and interpretation of data. The analysis of the responses to the open-ended questions, focus group transcripts, and end-of-semester perception questionnaire was based on the constructivist and interpretative method [20]. The analysis

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	PRE N = 109		POST N = 75	
	Mean	S. D.	Mean	S. D.
The product is easy to use	3.8	1.3	4.3	1.0
The product is attractive	3.2	1.5	3.6	1.2
The product is trendy	2.2	1.3	2.9	1.3
The product is novel	2.7	1.5	3.1	1.5
The product's price seems fair	3.5	1.5	4.0	1.1
The product is portable	2.2	1.4	2.8	1.4
The product fulfills its intended function	4.6	0.9	4.6	0.9
The product fulfills a critical customer need	4.3	1.3	4.5	1.0

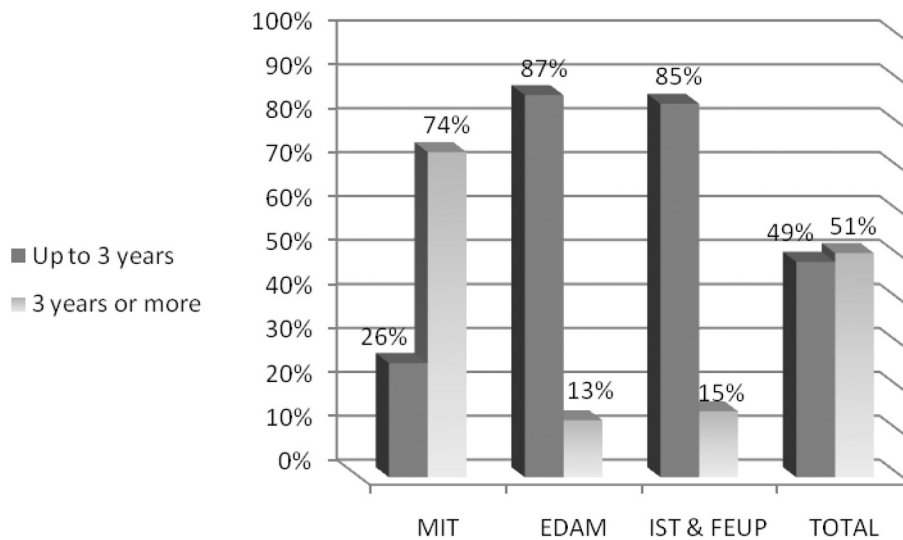**Table 3. Students' ranking of a product's critical success factors.**

Figure 2. Graduate students' distribution by their engineering work experience.

focused on students' thinking process and on the perceptions of both students and instructors. In order to produce reliable interpretations, data analysis was constructed gradually. The collected data was first read and processed, listing significant words, phrases, and sentences. We then categorized the data. All responses and transcripts were independently read and interpreted by three experts in engineering and science education. Throughout the analysis process, the suggested categories, views, and insights were examined and discussed, until consensus was reached.

Study corroboration and trustworthiness were established both by methodological and investigator triangulation [20]. Methodological triangulation was obtained by the convergence of data from three sources: (a) responses to close- and open-ended questions, (b) focus groups transcripts, and (c) written perceptions. Investigators triangulation was obtained by having the data jointly analyzed by the three experts.

Sample Products Resulting from Students' Projects

Examples of the products that the MIT teams developed as part of the PDD course were a battery integrated carry-on bag for frequent business travelers, a medicine dispenser with two compartments, remote keyless door opener, a task management system for blind people living with others, a rechargeable briefcase, and a rack for storing cans and bottles before taking them in for a refund.

Examples of project-based products the EDAM teams developed were "baby bottle anywhere"[2], a portable device to easily carry bags, a soap delivery system to help parents support children's hygiene, and a trash compactor.

Figure 3 presents the trash compactor which operates by exerting pressure on the compactor lid. The telescopic body will collapse as the bottles or cans are crushed.

The IST teams developed a device for exploitation of solar energy for glacier refrigeration, a cane with sensors for the blind (Portuguese patent DOM PT 1370), and an orange juicer for children.

Figure 4 presents the cane, which operates by detecting obstacles using an optical proximity sensor. When an obstacle is detected, be it a hole or a protrusion, the cane vibrates. Different vibration frequencies help the user know if the obstacle is a hole or a protrusion.

FEUP teams developed a solar energy supported baggage, a Web platform for storing medical data, and a social network for elderly people.

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[2]A baby bottle nipple that can be attached to any baby food package, dispensing the use of a baby bottle.
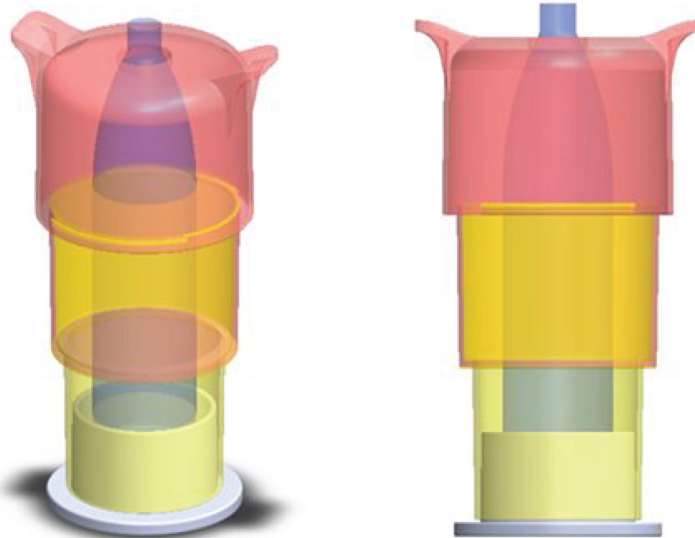
Figure 3. Trash Compactor—an example of a product developed by an EDAM team.

Figure 4. Cane with sensors for the blind—an example of a product developed by an IST team.

FINDINGS: LEARNING OUTCOMES

The findings of the questionnaire and their analysis are divided into three sections: critical success factors for creating a "good" product, product development activities, and individual and team skills.

Critical Success Factors for Creating a "Good" Product

To analyze changes in students' responses before and after the PDD course, we compared responses to several questions. One of the questions called for ranking critical success factors for a "good" product. Table 3 lists the pre and post average ranking on a 1-5 scale of the entire student population. The score of the post is consistently higher than that of the pre. The highest ranking items in both the pre and the post are fulfillment of (1) the product's intended function and (2) critical customer need. Trend, portability, fair price, and ease of use increased the most (0.7, 0.6, 0.5 and 0.5, respectively). These factors increased the most due to the fact that in the post-questionnaire, the students had to relate these factors to the product they had developed in the PDD course.

The next question called for ranking reasons for product success despite failing technical specifications. The pre and post responses for MIT, EDAM, and IST & FEUP are presented in Figure 5, Figure 6, and Figure 7, respectively.

Examining the responses, we see that overall, the ranking in the post-questionnaire is higher than that in the pre-questionnaire for all three groups. The highest ranking items for the three groups were "Fulfills its intended function" and "Fulfills a critical need", both ranking above 4. These are followed by ease of use and fair price. "Trendy" and "Novel" are low-ranking items. Statistical analysis of the relative differences from pre to post revealed no significant difference between the three groups for any one of the items. Based on this and the similarity of ranking we conclude that the three groups had similar understanding of the reasons for product success despite technical failures.
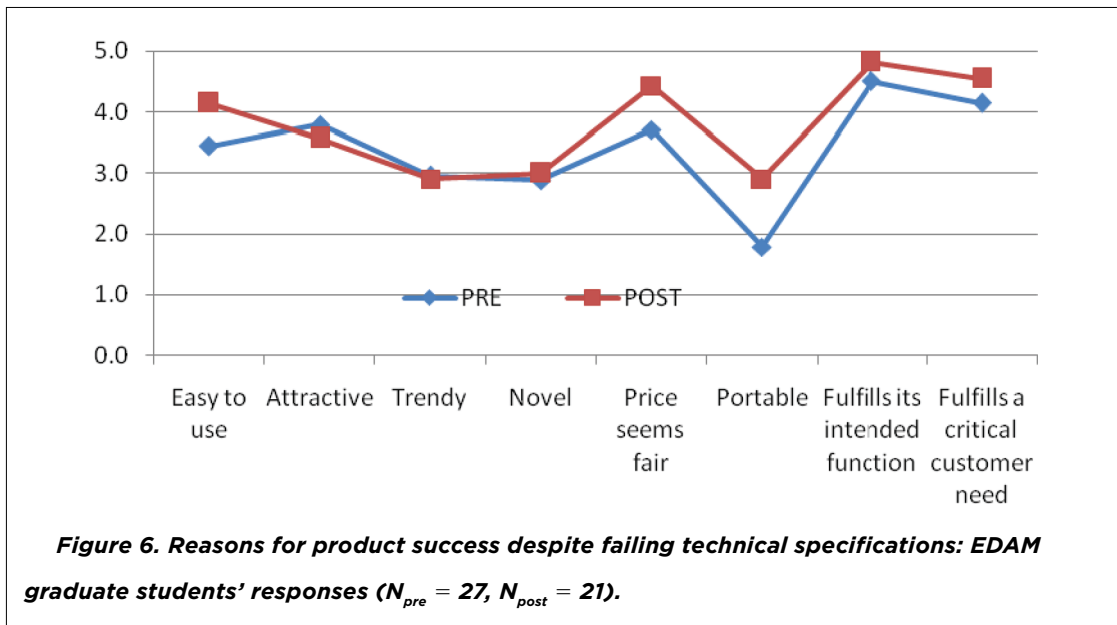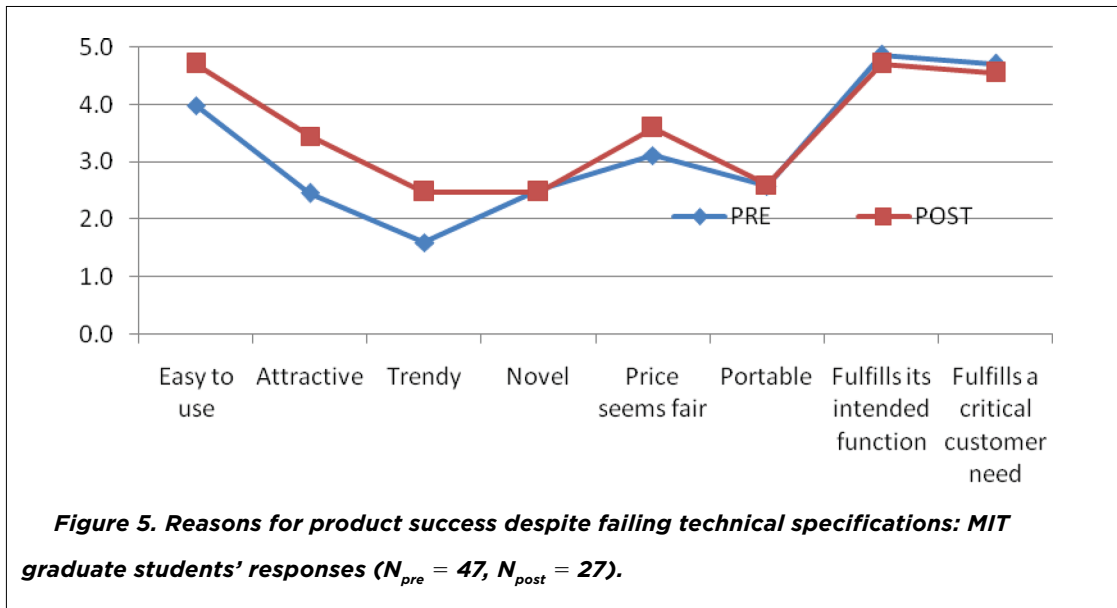
Product Development Activities

We analyzed two questions from the post-questionnaire that were related to product development activities. The first question was: "*List the activities that occurred in the development of the product your team carried out.*"

Following is the list of ten categories which emerged as a result of the item analysis and validation by three experts, arranged by the product lifecycle phases.
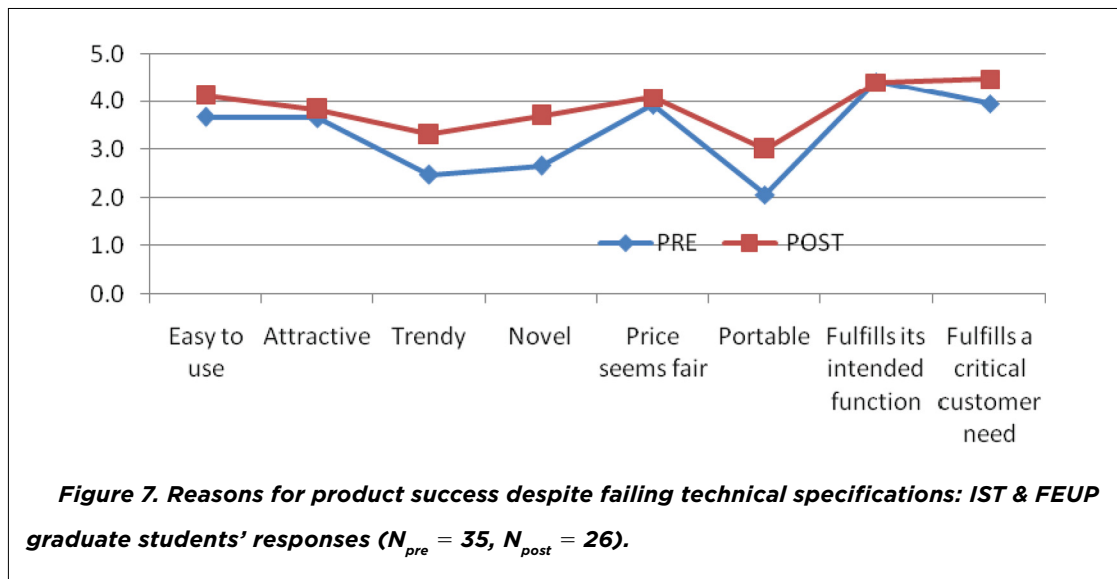
1. Social interactions—PDD-related team management, face-to-face or electronically-mediated meetings
2. Planning and brainstorming—including mission statement

Figure 5. Reasons for product success despite failing technical specifications: MIT graduate students' responses ($N_{pre} = 47$, $N_{post} = 27$).

Figure 6. Reasons for product success despite failing technical specifications: EDAM graduate students' responses ($N_{pre} = 27$, $N_{post} = 21$).

3. Concept development—including generation, selection, improving, and testing

4. Market research—survey, interview of needs, questionnaires, competitors research

5. Analysis & design—Project and product analysis, benchmarking, architecture, design

6. Prototyping—creating a prototype of the product being designed

7. Prototype testing—including experts or users survey

Figure 7. Reasons for product success despite failing technical specifications: IST & FEUP graduate students' responses (N_{pre} = 35, N_{post} = 26).

8. Product modifications and manufacturing
9. Business plan and IP—including marketing, patent, and risk
10. Presentations—students' class presentations of their designed product.

An example of a comprehensive response written by one of the MIT students is provided below with the appropriate score for each category (scoring one point for each statement related to the specific category).

"We wasted a lot of time deciding on a customer or market that we wanted to develop a product for. I think this was completely unnecessary as this is not what most companies do and it was not important to the learning process. We spent a minimal amount of time identifying customer needs. This part of the process really should have been much longer to really do this right. Once we identified a single need to address. We brainstormed concepts [concept generation] *to address the need. After we developed several concepts, we ranked them in a Pugh matrix and selected "the best" concept* [concept selection]. *We then improved this concept* [concept improving] *by adding positive features from the other highly ranked concepts* [concept ranking/testing]. *We then proceeded to create a detailed design for this concept. After the design was complete, we built a prototype of the design. [We] then performed basic product testing to determine if the product could satisfy our defined unmet need. After incorporating feedback from product testing, we refined the design and built another prototype. Again, we performed product testing on the second prototype. We also used this prototype to begin developing a user market.*

We incorporated feedback from the design into our final product. We will use quotes

from this final design to develop product cost and a manufacturing plan."

This student gave the highest rankings to the categories of Concept development [4 points – see comments in brackets within the quoted text above] and Product modifications and manufacturing [4], followed by Prototype testing [3], and Market research [2 points]. In Planning and Prototyping the student scored 1 point for each category, while Social interactions, Business plan and IP, and Presentations categories were not mentioned at all [0]. The point score reflect the number of different items we found in each category.

Table 4 presents the number of product development items listed by students in the post questionnaire and shows that overall students provided detailed responses. MIT and EDAM students listed on average a higher number of items than that of the IST and FEUP students. Since the items relate to the various stages of the product life cycle, a higher ratio of items per student indicates that the student has internalized the stages by engaging in their actual performance. Thus, it is a way of assessing the level of learning that took place. The MIT and EDAM students scored higher in items per student, indicating profound learning. This is also one indication of the effectiveness of the project-based learning approach compared with the more traditional approach used for teaching the IST and FEUP groups. The close equivalence of the MIT and EDAM students indicates that the "concentrated" curriculum in EDAM is quite effective (perhaps even more than the standard approach because the MIT students had more engineering experience).

Examining Figure 8, we found out that the two highest-ranking categories students listed were market research and concept development. These were followed by prototyping, analysis and design, and business plan and IP.

Comparing the distribution of categories in Figure 9 by the three research groups, we see that overall the pattern is similar, but there are some interesting differences. MIT students were more

| Research Group	N Items	N Students	Items/Student
MIT	218	26	8.38
EDAM	146	17	8.59
IST & FEUP	157	21	7.48
Total	521	64	8.14

Table 4. Number of product development items listed by students in the post questionnaire.

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Figure 8. Distribution of product development categories listed by students in the post questionnaire.

Figure 9. Distribution of product development categories in the post questionnaire by research group.
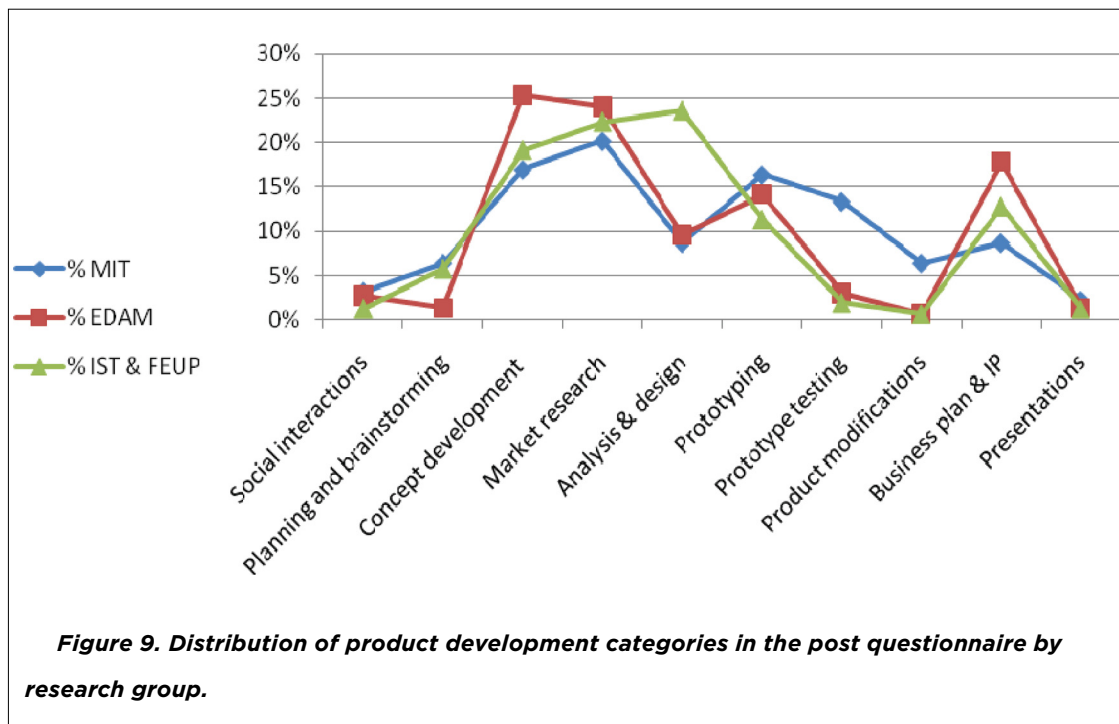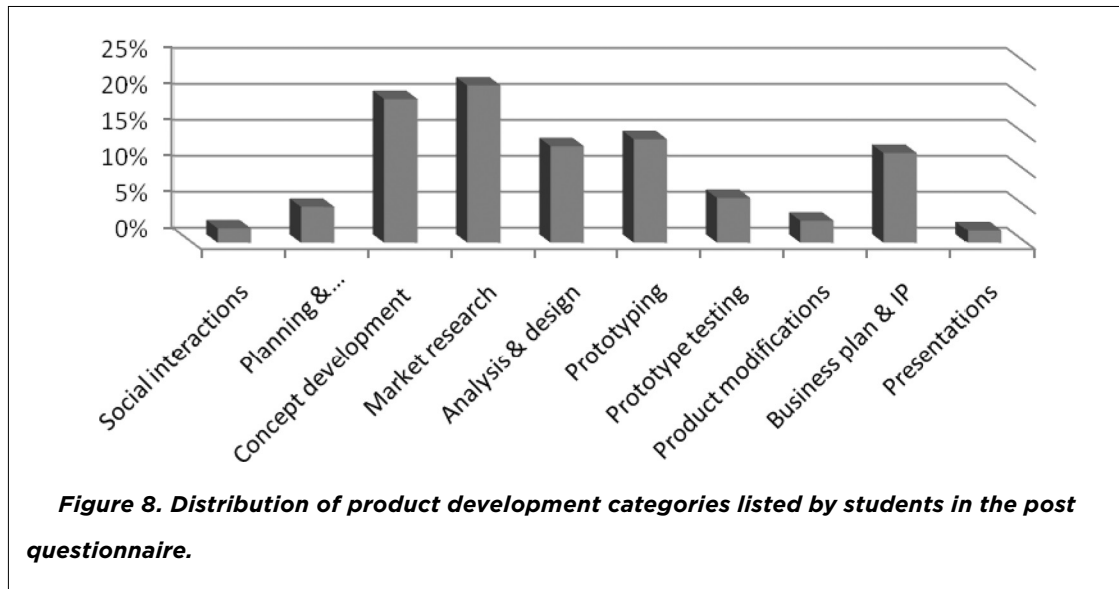
inclined to mention later product lifecycle phases, such as prototyping, prototype testing and modification, than their Portuguese peers. This has led to a more balanced approach to product development, in which every phase of the process gets proper attention.

Figure 10. Distribution of marketing and promotion categories in the post questionnaire by research group.
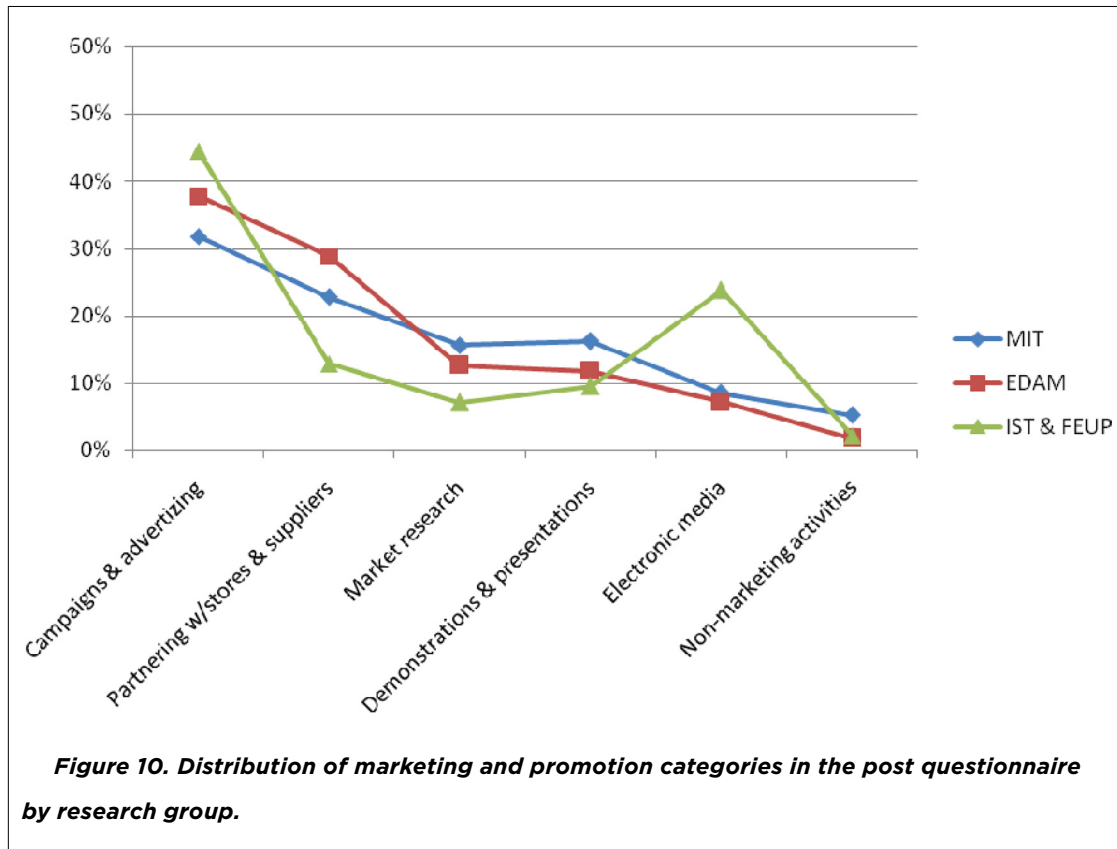
EDAM students were more focused on early stages of concept development and market research, as well as on later stages of writing a business plan and attending to IP issues. This focus is a result of the way the assignments were designed. During the first four weeks of the course (of which the first is devoted to intensive lectures), most of the basic concepts are introduced, and the students work intensively on them, with awareness of business aspects from the outset. In the second half of the semester, the workload decreases somewhat as the students approach the business plan preparation and final presentation.

Analyzing the influence of the course structure of condensed weeks of classes followed by periods without formal class meetings, we concluded that this had no effect on the overall performance of students. The percentage of time spent on social interactions is similar to that of the MIT students and higher than that of the IST and FEUP students.

The fact that the students stayed for a full week at the same location, in the same hotel, working intensively on their project is in itself a team building experience. This helped them communicate when they were dispersed later, during the two six-week periods without class meetings. Although

not explicitly asked in the questionnaire, in some informal discussions of the authors with the students, students indicated that most of their interaction during this six-week break was frequent, using email and Skype. The students acknowledged, however, that this working mode was made possible only after the team members had gotten to know each other well enough to freely use electronic means of communication. The faculty feedback on the students' assignments is also done electronically. Every assignment is graded and commented by the faculty during the two six-weeks periods without classes.

Comparing the MIT and EDAM students to the IST and FEUP students, we see that Analysis and Design was highest for IST and FEUP students. This may be a side effect of the background of these students. About half of them have a mechanical engineering background, where analysis is a key factor to their success in college. On average their work experience is limited (see Figure 2), so they rely on what they learn in the course to ensure that their project progresses as it should. This is also reflected later on in their lack of commitment to prototyping and prototype testing, an unfamiliar area for them, and one that is also not emphasized in the traditional course syllabus or the assignments schedule.

The attention to Business Plan and IP is critical for all of the Portuguese students. Both IST and EDAM students were mindful of IP issues, but in different ways: IST students filed a relatively large number of patents while EDAM students were encouraged to search extensively for prior patents that could impinge on their proposed products. MIT students were not encouraged to file patents, although IP issues were mentioned in the course. These differences in IP-related foci are reflected in Figure 9.

The second question related to product development activities, which focused on marketing, was: "*List in descending order of importance three activities that you would carry out in order to market and promote your product*." Since the question was open-ended, we analyzed the students' free text responses by setting categories, validating them, and classifying the items gleaned from the responses into these categories. Examples of students' responses to the above question and their classifications are presented below. The first activity a student mentioned (which s/he perceived as the most important one) scored 3 points, the second 2 points, and the third 1 point.

Example I presents an MIT student's post questionnaire response to the marketing and promotion question and their classifications:

"*Participate in Trade Show* [Demonstrations & presentations category – 3 points], *Run Advertising Campaigns* [Campaign and advertizing category—2 points], and Connecting with retailers for product distribution [Partnering w/stores & suppliers category— 1 points]."

Example II presents an EDAM student's post questionnaire response:

"*Get it out to the customer (samples, conventions, etc.) If they love it and need it, more will want it and buy it* [Campaign & advertizing category – 3 points], *Form a partnership with a distributor and turn-key manufacturer* [Partnering w/stores & suppliers category – 2 points], Improve our website and other marketing media [Electronic media – 1 points]."

Example III presents an IST and FEUP student's post questionnaire response: "Offer some trial kits for some people [to] try our product [Campaign and advertizing category – 3 points], Web-site and publicity on the radio [Electronic media – 2 points]."

As Figure 10 shows, the overall response pattern of the three research groups is similar. The similarity is most apparent between MIT and EDAM. This again indicates very similar learning experiences in the very different learning modes. On the other hand, IST and FEUP students place more emphasis on campaigns and advertising using in particular electronic media. IST and FEUP students have market research and supply and demand chain partnership scores lower than those of their MIT and EDAM peers. From a product development perspective, IST and FEUP students rely more on downstream commitment from marketing campaigns than on upstream market studies or on integrating product development with strategic decisions from the company. These differences can be attributed to the fact that IST and FEUP courses were mostly theory-oriented and lacked practice in being engaged in an industry-like environment.

Individual and Team Skills

The questionnaire included two open-ended questions related to individual and team skills. The first question, aimed at understanding students' views on team skills necessary to develop successful products, was phrased as follows: *"What two most important TEAM skills are required while working on a product development project?"* Figure 11 presents the results. In this question, as in the previous one, the IST and FEUP group deviated from the similar pattern exhibited by the MIT and EDAM groups. IST and FEUP students estimated the importance of project management and organization, which is a critical topic in developing new products, to a lesser extent than their MIT and EDAM peers. In the pre-course questionnaire, creativity and open-mindedness were ranked by the IST and FEUP group higher than by MIT and EDAM. This is likely due to differences in these students' backgrounds. Indeed, as Table 1 shows, IST and FEUP students included designers and architects, who are typically known to consider these traits as important more than engineers do. In IST, creativity is especially emphasized, and an entire lecture is devoted to this subject, a fact that probably contributed to these differences between the groups.

Figure 11. Distribution of team skills in the post questionnaire by research group.
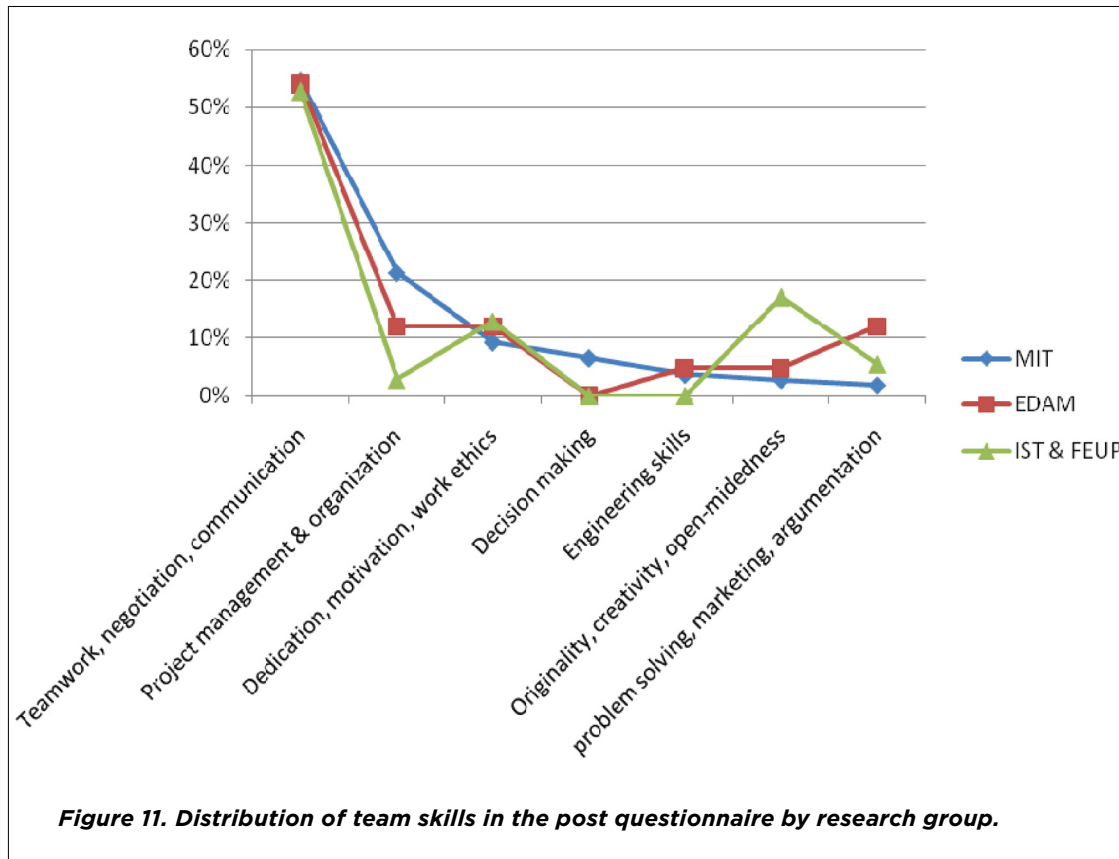
Similar to the first question, but relating to the individual skills as opposed to team skills, the second was as follows: *"What two most important INDIVIDUAL skills are required while working on a product development project?"* Figure 12 shows the results of the analysis of students' responses to this question, indicating substantial differences between the three research groups. It seems that IST and FEUP students misunderstood the term "individual skills" within a product development team, taking it to mean individuality or individualism. This is especially noticeable in Figure 12 for the low scores IST and FEUP students gave to teamwork, negotiation and communication (the first skill) and to leadership (the sixth skill). IST and FEUP students indicated engineering skills as being important more than twice as many times as their MIT and EDAM peers. This too can be explained by the difference in the groups' professional composition – IST and FEUP students lacked professional engineering experience and therefore emphasized the need for it at the expense of teamwork, as they felt a lack of engineering experience during their project work.

An interesting difference exists in the view of EDAM students on originality, creativity and open-mindedness between the team and the individual. The students attribute this skill almost entirely to

Figure 12. Distribution of individual skills in the post questionnaire by research group.
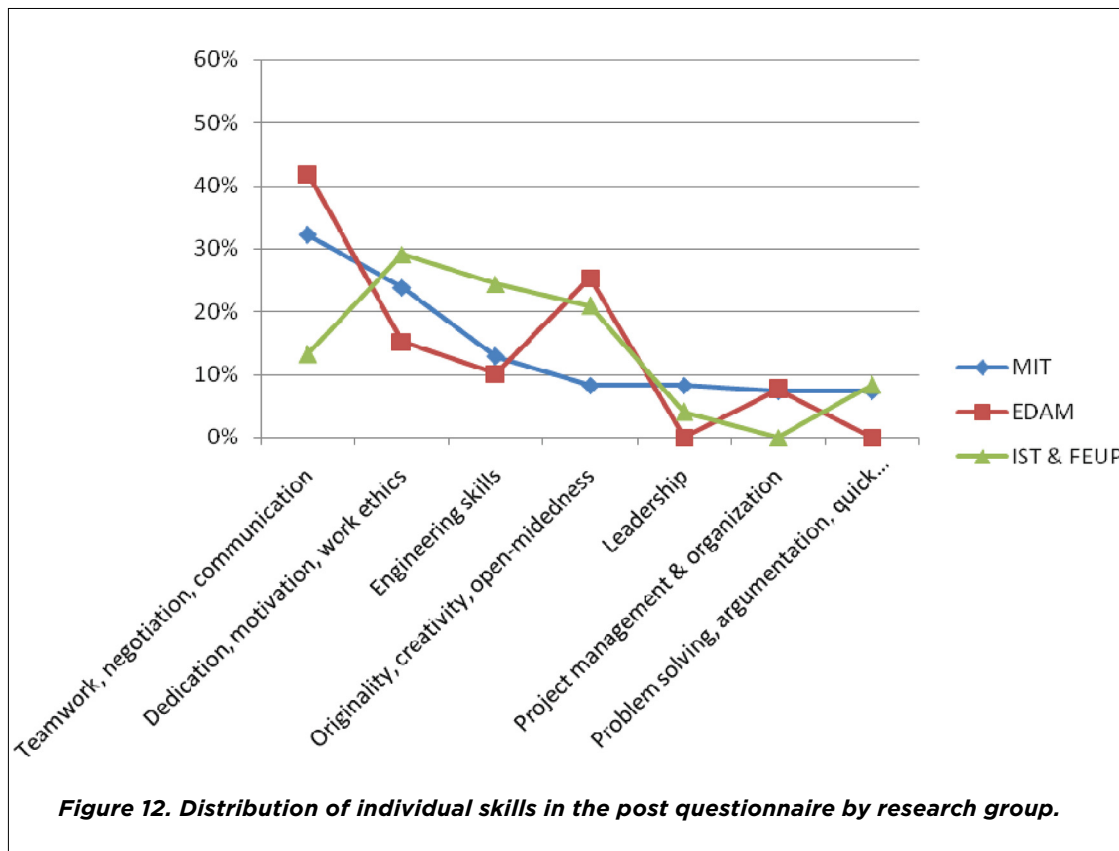
the individual and not to the team. The pattern for MIT students, while similar, is less drastic. For IST and FEUP students there is hardly any difference between originality, creativity and open-mindedness of the team and the individual. It is suspected that these results (more than other differences between groups found in the study) reflect cultural differences between Portuguese and American students.

PERCEPTIONS OF STUDENTS AND FACULTY

Students and faculty perceptions were gathered from two sources. The post-questionnaire contained a question in which students were asked to list advantages and disadvantages of the project-based learning approach (for MIT graduates) and of the EDAM program (for EDAM graduates) in respect to their PDD courses. The second source was focus groups with EDAM students and faculty. Examples of MIT and EDAM students' responses are provided below.

MIT Students' Perceptions

MIT students provided several insights into the contribution of project-based learning to their career. One student said:"*I think that project-based is the best way to learn in PDD class as it leads students to think about how to apply the knowledge in the project. Lecture-only approach will not be beneficial if we don't have to work on any project in class.*" Advantages listed by another student included: "*Apply the classroom directly to the project*. [We gained] *real hands on experience and outside the normal job description. Liked getting hands dirty, and going out to field.*" Yet another student provided additional benefits: "[We] *go through a complete cycle of development; Hands on experiences with each activity and their importance.*"

The combination of teacher- and student-centered approaches was well received: *"Frontal lecture-only approach was useful when we learn something new such as concept generation or selection methods. On the other hand, project-based learning approach made us stay active throughout the entire semester. Also the experience that we learned from our project gave us a very clear connection to the knowledge that we learned from lectures."*

Main disadvantages students noted included: (1) *"There was a huge learning curve that took a lot [of] time for the project…* [We] wanted to learn material better, but [were] *focused too much on project.*" (2) "[We] spend too much time on the actual prototyping phase. *Does it add to the learning experiences? Only skim through each phase so no deep learning experiences." (3) "Some products will fail, not all of tools presented in the class get used…*" (4) "*Different time schedule (difficult to manage sometimes)—Some team member commitment - Differences in expectation.*"

EDAM Students' Perceptions

EDAM students were more articulate, intertwining the positive and negative aspects of the condensed program. One wrote that for students who keep their day job this format is the best but highly demanding: *"The intensive lecturing periods are the best for those (like me) that have a job during the EDAM program. But the Saturday with classes is very difficult to manage because we are all week out of house and we have a family and children to take care. By the other side the full-term lecturing allow us to organize very well all the work, because in the intensive lecturing periods we have to[o] much work to deliver at the same time… [Need] a well Organize[d] schedule between courses for deliver*[ing assignments]."

Other students commented on reading materials: (1) "*I think this method is quite good even though sometimes I have a hard time keeping up with the pace when there are a lot of things to read and prepare. Nonetheless that's something I have to improve and not something the program has to change. What I dislike in this method… if there's a good chance that the persons on the class already heard about a given subject, it's preferable to give a case study approach…*" (2) "*Given the*

intensive nature of the lecturing periods, volume of information can be overwhelming during classes, and there is little time to think about subjects between sessions. The weeks between lecturing periods allow us to schedule research according to individual study methods and timings. This second semester some readings were sent to students prior to lecturing period. That was positive, since we were introduced to subjects in advance."

We note that, even in classes that take place during 15 consecutive weeks, reading is a problematic issue especially for graduate students who keep working in the industry during the course.

A Ph.D. student discussed acquired skills and project-based learning even though this was not directly asked: "*The intensive lectures are a good opportunity to develop our skills to plan, organize and study the materials before the lessons... I can be more effective and focused in my work...The students need to express their thoughts more effectively, perhaps with more visual thinking. The role of concurrent development of the projects (or thesis) is an excellent way to learn new knowledge (project based learning)...*"

EDAM Faculty Perceptions

During November 2008, EDAM Faculty from three universities, IST, FEUP, and UM, met one of the authors in Portugal. They were asked to comment on advantages and disadvantages of the EDAM program's intermittent lecture structure, and to compare it with the typical full-term lecturing structure they teach in other programs. Some of their responses, quoted below, indicate that this unique format has the advantage of getting commitment from faculty as well as students. Faculty D noted:

"*I find this lecturing scheme very good for me. I did not get relieved from my previous lecturing duties in my "normal" courses* [at the university], *so the intensive lecturing of EDAM minimizes the disturbance with the other... three different courses* [I teach] *besides EDAM. This political compromise of going from one university to the next to teach the several week lectures turned out to be very good in terms of commitment from faculty, since we need to move with the students when the lectures do not take place at our home institution, so we [faculty] also spend time that is totally devoted to the course we are teaching, with minimum interruption from other issues – it's a 'mini-sabbatical', if you wish to call it that...*"

Faculty G added the students' perspective:

"*I think that the one intense week has the advantage of the students being completely concentrated in the program, and not disperse with their company problems. The fact that they are away from their job place is also very important for their success in the program.*

This is not common in the Portuguese system… but after a period students will find great advantages in this system…"

Another advantage of the non-consecutive learning pattern was pointed out by faculty L: "… *It allows re-discussion of the topics of the first lecturing period after a reflection on it or its implementation, define more structured assignments, promote team working during the assignments… and it minimizes faculty [schedule] conflicts.*"

Linking academia with industry was raised as an advantage by faculty T: "…*the main advantage is the bridge between industry and university. The time used during the semester is very concentrated in two hard weeks. It is difficult for the students from the industry to get all the assignments on time. PhD students are more invested in the learning but they* [the professors] *try to combine them* [full time students with those who have jobs in industry] *together. The contact between the students and the faculty is very short and sometimes* [it] *is not easy to understand clearly what the real work of the students is."*

One concern EDAM faculty mentioned was overload, as faculty O. noted: "*They (the faculty) are doing everything as before, but in addition… they also teach PDD in collaboration with other faculty because it is* [an] *interdisciplinary program and requires more expertise. The load is much higher for EDAM than for a regular* [program]*."*

SUMMARY AND CONCLUSIONS

This study assessed the PDD course within the MIT-Portugal Program. The research questions were to investigate the PDD EDAM course in the context of two other groups who studied the PDD course – MIT and IST and FEUP. The MIT students studied a project-based semester-long PDD course. The EDAM students took an intensive modular course, taught in a condensed schedule with emphasis on project-based learning. The other group from Portugal took a more traditional, semester-long course.

While we found similarities among the different student populations in a number of areas, there were also some interesting differences. The three groups had similar understanding of the reasons for product success despite technical failures, and they all ranked highest the following items: 'the product fulfills its intended function' and 'the product fulfills a critical need'.

In an open-ended question related to the various stages of the product life cycle MIT and EDAM students listed on average a higher number of items than that of the IST and FEUP students. A higher ratio of items per student indicates that the student has internalized the stages by engaging in their actual performance. Thus, it is a way of assessing the level of learning that took place.

The findings obtained from the focus groups and the end-of-course perception questionnaire and the fact that the EDAM students' responses were closer to those of the MIT students indicate that the PDD course has had a positive impact on the EDAM students. The unorthodox lecturing scheme of two one-week intensive classes with a six-week break caused no major disturbance in student learning. Indeed, there are some indications that it might be superior to conventional academic practice and further exploration of this concept in other settings is recommended. Teamwork did not suffer from having to carry out the assignments by geographically dispersed team members, but the need of team members to know each other in person prior to the beginning of the teamwork has been found to be critical. Hoegl and colleagues [21] found that effective teamwork is paramount if the distance between team members increases. Furthermore, if the team can achieve a high level of teamwork over distance, a low-proximity team can attain a higher level of effectiveness and efficiency than a co-located team for the same tasks. In general, this mode of teaching more closely matches some aspects of professional practice and thus matches with the goals of PBL. This finding also presents an opportunity for potentially improving remote teams' effectiveness in new product development that should be further explored.

The formation of teams in EDAM with a mix of technology (LTI) and management (TME) students also seemed to work well. A mix of some industrial experience with fresh scientific knowledge was noticeable in the project outcomes, and students learned a lot from the experience of working with peers with diversified backgrounds. The questionnaires revealed differences in terms of cultural, professional, and educational background. This was also found by [22], who compared different teams in different countries on issues related to the perceived success of new product development in the context of higher education in technology management.

Engineers face design tasks that are growing in complexity, demanding knowledge skills that cut across several traditional knowledge boundaries. These design problems call for broad-based collaboration skills. Researchers [23] found that there are learning barriers stemming from students failing to recognize the relationship between their own discipline and an interdisciplinary subject of study and failing to recognize and value the contributions of multiple technical and non-technical fields to a given interdisciplinary problem. Overall, however, our observation was that MIT and EDAM students were able to overcome this difficulty.

Students' achievements in their learning tasks depend, in part, on the match between the teaching pedagogy and the learning processes students experience in their courses [24]. Many studies on higher education confirmed the benefits of student active learning and engagement [25, 26]. Prince [27] noted that the most important student engagement in an active learning setting was the personal interaction, both among students and between faculty and students.

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The project-based learning approach that follows the MIT PDD course example has been instrumental in successfully incorporating hands-on activities and students-faculty interactions into the formerly teacher-centered Portuguese approach.

Researchers [28] have emphasized the importance of team coaching and its relevance when teams are formed of individuals that are very different in their cultures, languages, and/or backgrounds. To some extent, the EDAM PDD students are different in all three elements. EDAM PDD faculty must consider themselves as the students' coaches. This additional role requires extra time and effort to provide students with periodic and timely feedback on students' assignments during the two six-week periods, and toward the end–on the students' final projects. Authentic learning processes normally require a certain level of effort, and this is true for both students and teachers. However, specific measures will have to be taken in order to avoid excessive overloading of both the students and the teachers of the MIT-Portugal Program [29].

Reflecting on the EDAM team mission statement, as specified by Magee and colleagues [2], the EDAM PDD course is one important step in advancing the new educational engineering paradigm in Europe in general and in Portugal in particular. This innovative program and its unique curriculum help promote a new attitude towards entrepreneurship, knowledge-based manufacturing, and competitive product development.

In conclusion, as the National Engineering Education Research Colloquies [30] and others [31] noted, successful studies in engineering education are expected to be comprised of multidisciplinary teams of engineers and other fields in order to bring their expertise to this emerging field of research. Indeed, the research team who carried out this study consisted of science education and engineering experts from two different universities in different countries. Just as it has been found valuable to involve interdisciplinary teams of students, our research has demonstrated that there is merit in collaboration among faculty from different countries with various backgrounds and disciplines. This seems to be an adequate response to the globalization challenge engineers face, as pointed to by Vest [1]. Further longitudinal studies are needed to strengthen our experience and claim that there is benefit in creating multidisciplinary teams of both students and faculty.

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