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Interdisciplinary Learning: An Electronic and Computer Engineering Case Study to Solve Environmental Problems*

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Environment and sustainability, and Principles of Economics are subjects present in engineering courses in Brazil. To attract the student's attentions to these subjects and promote entrepreneurship fomenting, an experiment was developed with electronic and computer engineering students aiming to use interdisciplinary and project-based learning approach. The students, fifty-six students in the first version and fifty-seven in the second one, formed mixed teams, with the goal of developing a prototype and a business plan to solve a specific environmental problem. During the prototype development, the teams presented technical reviews based in system engineering approach, which exposes the student to real industrial practices, even though assessed by grades. It was a four-month experience ending with the team presentation to professional experts in evaluating start-ups proposals. The experiment was successfully applied in two academic years with minor adjustments between its first and second versions. The article presents the interdisciplinary approach of the experiment, the assessment method, and feedback given by the students, instructors and invited professionals.

Keywords: interdisciplinary; engineering curriculum; environment; sustainability; economics; project-based learning

1. Introduction

The growth of the human knowledge forces the need for interdisciplinary skills with engineering activities, project developments and team requirements [1]. So, the use of new approaches in Engineering Education is being proposed and studied continuously. [2] presents the use of Project-Based Learning (PBL) integrated with design review meetings to mirror industry demands in an embedded system course. [3] uses the approach of an international university competition consisting of designing, manufacturing and competing in formula-type vehicles. Even though the competition is related to the university's environment, it is being driven by the demands of business. The use of interdisciplinary and/or multidisciplinary approach conjugated with PBL and Hands-on activities is very widespread in engineering education [4–7], with successful implementations.

Entrepreneurship and innovation have also received attention as fundamental aspects for economic growth and development [8]. Creating an enterprise culture, which leads to the development of small businesses, is a challenge for many development agencies, government departments, and educational and training institutions. Engineering courses, in general, do not strength the business knowledge. This way, the opportunity to face an entrepreneurship experience contributes for creating the enterprise culture. As an example, [9] presents a review in Civil Engineering curriculum to further improve its entrepreneurship education, due to a state guidance, which is concerned in producing engineers who create jobs rather than engineers who are looking for jobs. One guideline presented is such that students should even be encouraged to start their own enterprises before they graduate. [10] employed a methodology which aims to transform the teaching act in engineering in such a way that it allows the development of creativity, innovation in the technological area and also the enhancement of accountability of graduates.

In engineering curriculums, the application of interdisciplinarity among disciplines of the technical core is widely described in the literature [1–7, 11–15], the same is not true among technical core, business disciplines and yet, an interdisciplinar discipline, such as Environment and Sustainability [9, 10]. Aiming to propose a new experiment in engineering education aligned with the approaches that are being studied and, in many cases, successfully applied, the authors planned and implemented an interdisciplinary and hands-on experiment. In this way, the innovation proposed in this experiment, anchored in established interdisciplinary courses experiments, is to work with technical core and business disciplines promoting entrepreneurship education to seniors engineering students. In this proposal, the students are led to work in both roles, as economists, understanding how the markets work, and as engineers involved in the development of a technological product, designed for solving an environmental problem, through an economically viable venture.

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2. Problem statement

Traditionally, courses are planned in the disciplinary approach obeying a curriculum in which the knowledge to be studied and learned is divided in self-contained subjects, isolated from the other topics that are being studied in the same academic period. This is a good approach in several subjects, focusing in one matter until the student dominates its basic concepts and necessary tools. As noted long ago, "understanding the disciplines is therefore essential to good teaching, for the disciplines, are the key to knowledge and methods of inquiry that have demonstrated their fruitfulness in learning." [16].

The interdisciplinary approach has many variants starting with "disciplines contributing on a common subject" to a "collapse of academic borders and the emergence of a new discipline" [17, 18]. Interdisciplinarity in this article considers the interaction among disciplines by establishing and developing connections among them, maintaining their integrity. This way, the approach follows the consensus definition of interdisciplinarity according to [19], as a work shaped by disciplinary interaction, disciplinary integration, and the presence of an overarching problem, topic, or theme.

In engineering, interdisciplinarity is an appropriate approach, since an engineer frequently works in teams with members of different skills, as the problems to be solved normally involve a wide range of concepts, i.e. interdisciplinarity occurs naturally among disciplinary specialists [17]. The same is also true for the instructors in an interdisciplinary approach, as they have to form a team teaching [20].

Nowadays, subjects as environment, sustainability, and economics are part of the Curriculum of Electronic Engineering and Computer Engineering Curriculum [21–27]. In the context of traditional Brazilian engineering courses these subjects are usually considered the self-contained fields of knowledge. However, recently at the Technological Institute of Aeronautics (ITA) it has emerged a new perception that it should be necessary to associate, Environment and sustainability, and Principles of Economics, with real engineering problems. It was considered a relevant problem, and during the planning of possible solutions, it was identified the opportunity in simultaneously address the problem of fomenting entrepreneurship in engineering courses, which is a current issue.

3. Experiment development

Fig. 1 presents the interdisciplinary activities involved in the experiment. The key element is a hands-on activity, which consists in the development of a business company formed by students with electronics and computer background. Two regular courses, Environment and sustainability and Principles of Economics provide the complementary knowledge for the Company.

Environment and sustainability gives the skills to analyze and solve the problem in the area, and Principles of Economics deals with the business activities. The last activity consists in an evaluation of the business plan and prototype developed to potential angel investors. This experiment was only possible due to ITAEx, an initiative of Alumni of ITA, that provide funding for educational related activities [28].

3.1 Planning and applying interdisciplinary

The interdisciplinary activities were conceived to work with the specific projects and study cases in which the students' skills are applied to solve or

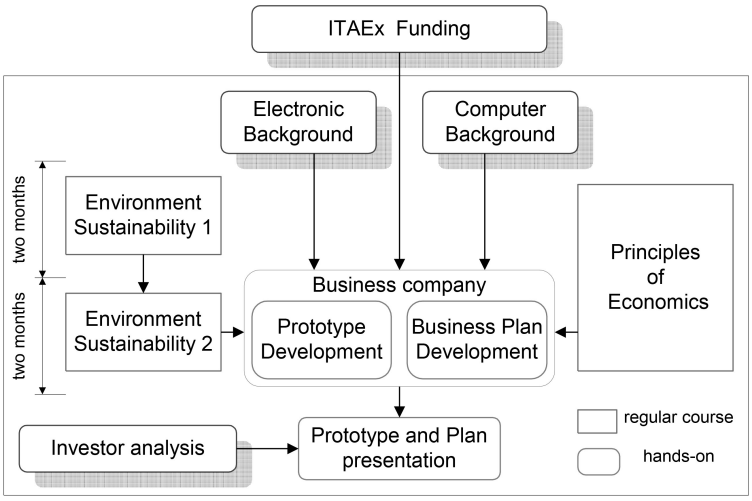

Fig. 1. Interdisciplinary experiment—subjects and goal.

mitigate environment sustainability problems. The approach of hands-on activities during the last two months was the desired goal.

The first step in the hands-on approach started a semester earlier. It consisted in defining a simple set of devices, which could be used to propose systems to address different problems related to environment. Once defined the set of devices, the project was presented to ITAEx and competed for funding with other projects. The two versions of this experiment raised the requested funds.

There were also meetings among the instructors to schedule the activities along the following semester, see Fig. 2. Along these meetings, it was discussed the main deadlines. The main activities in first two months were the theory development, training with applied exercises and project definition.

In the last two months, the students should develop the project, adjust the economic plan and Canvas, and prepare the angel investors presentation using all these materials.

3.2 Environment and sustainability course planning

The course structure considers that environment and sustainability have become increasingly important and engineers should have skills to analyze and propose solutions to solve or mitigate the problems related to the area.

During the first two months of the course, the concepts related to the area were presented. Topics in ecology and aspects of economic development and sustainability were taught to show the link among economic growth, sustainability and Earth's resources.

In the first version, the last two months consisted in lectures invited to expose to the students the professional life aspects related to environment and sustainability, entrepreneurship and product development. In its second version, the lectures were invited in the first two months. In the last two months, the students were more dedicated to the prototype development. In both versions, during the last two months an instructor with experience in developing products advised the company's owners with the starting up process. Concerning technical issues, the prototype developing process was followed up by design review meetings, specified deliverables dates, and appropriated documentation generation, mirroring industry demands.

3.3 Principles of economics course planning

In this context, Economic Principles, which is a course usually designed to provide a basic understanding of the principles of microeconomics and macroeconomics [29–31], was adapted to introduce the start-up entrepreneur as the main stakeholder of the course. Thus, microeconomic models about decisions made at the consumer or firm level help students to understand the main principles that guide their clients' decisions, as well as their own production decisions, while looking for maximizing their profit. The industry analysis provides concepts to understand how and why decisions of the various

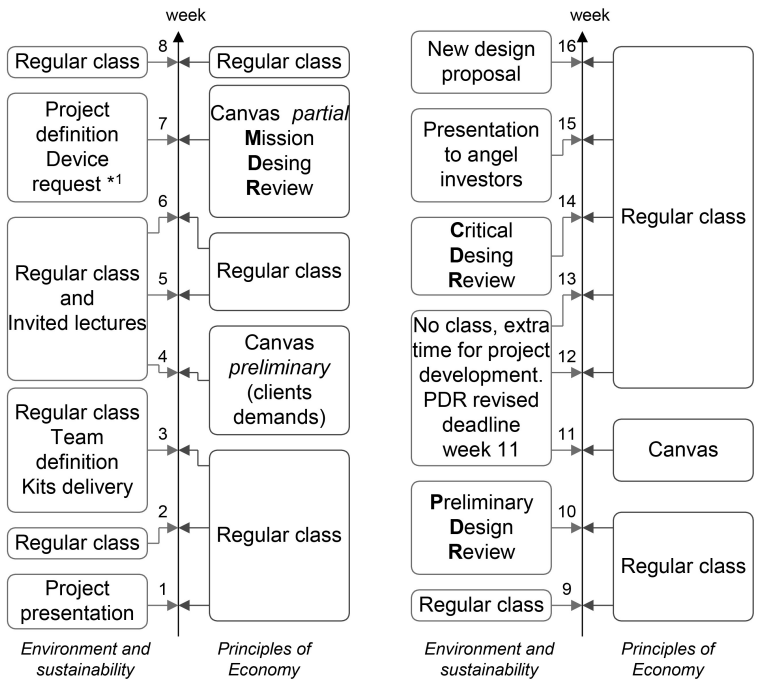

Fig. 2. Course activities and deadlines in the second version. (*[1] only in the second version)

agents that interact with one another in the market may affect student's decisions, as entrepreneurs. Since in the real life, the product lifecycle is more complex, there were introduced highlights about such production function, as well as about the costing and pricing principles and methods, utilized at the firm level. There were given also a set of financial concepts, aiming at obtaining financial viability indicators for the developed product. Finally, Macroeconomic principles were introduced expecting to improve the students' understanding of the influences of macroeconomic conditions over his product performance. Such interdisciplinary approach has motivated relevant changes for the Principle of Economics discipline, widening and deepening the usual approach for economic analysis of new ventures.

3.4 The company, business plan and prototype

A mixed team of four to six students of electronic and computer engineering composes the company. The students have to identify an environmental problem and propose a technical solution to it, employing an electronic computer based system.

The students employ their background in electronics and computer for the prototype development. An instructor is available to give them some technical guidance. However, the proposal and the solution development are responsibilities of the student.

While developing the prototype, the company should make a market analysis and prepare the business plan to launch the developed solution. These two activities motivate the students to apply the concepts just learned in Principles of Economics and in the invited lectures

3.5 Hands-on activities—first version

In the first version of the interdisciplinary experiment, the devices available to develop the prototype were previously established.

This experiment took place in the fourth year of Electronic Engineering course (30 students) and the fifth year of Computer Engineering Course (26 students) at ITA. The 56 students created 13 companies, which should develop a prototype of an environmental monitoring system. The system's functionalities consisted of: monitoring humidity and temperature of an environment; transmit the data via a wireless connection to a remote central; present the collected data in real time; and generate a data bank with the received information. The team of students could also propose another system related to the environment and sustainability problem. In this case, they should provide the devices for the system. The type of business to be exploited by each team is presented in Table 1.

3.6 Hands-on activities—second version

In the second version, the student teams were defined earlier, as well as the devices availability. The students (21 of the fourth year of Electronic Engineering Course and 36 of the fifth year of Computer Engineering Course) formed ten teams and each team pointed the business to be addressed and the need for different devices to accomplish it. Table 2 presents the team's compositions, the devices to be used and the project proposals.

As can be seen in Table 2, one team did not accomplish the requirement of diverse professional components (all team integrant were Computer engineer students). Even though the grade penalty was not severe, it was present in the final grade. The project proposals were diverse and related to Environment questions. They were evaluated by the instructors considering its environment and sustainability aspects, budget constraints and purchase time.

3.7 Invited lectures

In the first version, Entrepreneurship was one of topics of the invited lecturers. It was uttered by three experienced professionals, presenting cases, experiences as startup partners, and experiences as managers of business incubators.

Another invited lecturer addressed reliability. Since the proposal was the development of a prototype meant to become a commercial product, reliability and its market implications are an important subject to be considered.

In the second version, an invited lecturer talked about waste management due to the importance of electronic waste management. In another one, an entrepreneur lecturer was invited. He works with

Table 1. Teams and Project Proposal—First Version

Team	ELE students	COMP students	Project Proposal
G1	3	3	Monitoring for House garden
G2	3	1	Monitoring for small and big farming
G3	3	1	Monitoring for small farming
G4	3	1	Monitoring for big farming
G5	0	4	Collection of environmental data
G6	2	2	Monitoring for farming irrigation
G7	3	1	Monitoring for farming irrigation
G8	2	2	Collection of environmental data
G9	2	2	Collection of environmental data
G10	4	1	Collection of environmental data using UAV
G11	1	3	Collection of environmental data
G12	2	3	Monitoring for House garden
G13	2	2	Monitoring for farming irrigation

Table 2. Teams and Project Proposal—Second Version

Team	ELE students	COMP students	Sensors	Project Proposal
G1	2	4	Humidity, temperature	Home garden monitoring
G2	2	4	Temperature, carbon monoxide (CO) and turbidity of water	Monitoring of pollution of water sources
G3	1	5	Temperature, carbon monoxide (CO) and humidity	Monitoring for fire alerts and prevention
G4	1	5	Humidity, temperature	Monitoring for soil quality analysis
G5	4	2	Humidity, temperature and carbon monoxide (CO_2)	Monitoring study environment to maximize student performance
G6	1	5	Humidity, rain and temperature	Pivot irrigation control (monitoring system)
G7	2	3	Carbon Monoxide (CO), Methane (CH_4),	Monitoring of exhaust gases for automobiles
G8	5	0	Humidity, temperature and smoke	Monitoring for field irrigation
G9	1	4	Carbon Dioxide (CO_2), Methane (CH_4) and temperature	Monitoring of exhaust gases for automobiles
G10	2	4	Solar Cell, temperature	Study of efficiency and solar panels given its installation location

environment technological products and has his company currently in a business incubator.

4. Assessment

The grading of the students included conventional assessments like exams, team reports, team oral presentations and team projects. These evaluations allow the students to improve diverse type of skills. Besides that, a presentation to simulated angel investors bank was also part of the assessment of the pretense startup work aiming to launch a product in the market. The evaluations conducted during the experiment is detailed below.

The Principles of Economics course had individual evaluation based on written exams in almost the whole semester. However, during the semester, the teams were developing the business plan to the product to be presented to the angels' bank. The business plan presentation and the angels' evaluation were part of the students' final grade.

The evaluation of the Environment and Sustainability course was made by two instructors, considering the first two-month and last two-month activities. The first two-month grades were based on teamwork, in which the assessment items were an oral presentation, theoretical content and the approach used to develop the environmental subject matter. During the last two-month, the technical prototype was developed following some pre-determined steps, using System Engineering practices, specifically technical reviews in the project documentation. There were some established technical review documents and some of them are used in the prototype development: **MDR**—Mission Design Review, **PDR**—Preliminary Design Review, and **CDR**—Critical Design Review. The advantage of the System Engineering is that the students are urged to develop their prototypes by steps, identifying problems and having time to fix them. Beyond this aspect, it is also important that the students have this experience of developing a prototype as real as possible. So, the use of these technical reviews (from the Systems Engineering) exposes the students to real industrial practices.

The presentation to a simulated angel investors' bank is a kind of innovative assessment. Even though it is a pretense investor bank, it is composed by seniors engineers graduated at ITA developing activities in evaluating and funding engineering projects and startups. The investors proposed a list of items to be evaluated in a five-minute presentation given by each team of students. The items evaluated were: commercial availability, technical availability, economic and financial availability, innovation, and presentation time. The items evaluated by the angles' bank are previously known by the teams. The investors had previous access to the documentation furnished by the companies, not restricting their evaluation in the presentation. Each investor has 25 ITAcoins (fictional currency) to invest, which could be invested in only one company or shared among the companies. Table 3 presents one example of team's evaluation done by one investor.

Related to the angels' bank evaluation, it was noted that experienced professionals in analysis of proposals for investments should do questions which are beyond the courses scopes. In this way, the students are not able to answer all questions. As an experience to the students, who intend to be entrepreneurs, these type of questions make the difference, because they are exposed to problems and business aspects that do not study in the

Table 3. Example of the company's evaluation done by one of the investors

Angel: NAME								
Grades: 0 to 10								
		Commercial Availability	**Technical Availability**	**Economic and Financial Availability**	**Innovation**	**Presentation Time**	**Total of Points**	**I will invest (ITAcoins)**
Team	**Company name**							
G1	Hortus	8	8	7	7	7	37	
G2	Pure Water	7	8	7	8	7	37	
G3	SiGiC	9	9	6	9	7	40	
G4	Tec Horta	8	9	9	9	8	43	11
G5	Smart Climate Control	8	8	8	8	7	39	
G6	Irrigação Inteligente	8	7	6	8	7	36	
G7	Exhaust Control Device	9	9	8	8	7	41	7
G8	GreenFarm	8	8	6	7	8	37	
G9	QualiAir	9	9	8	8	7	41	7
G10	Solaris	8	7	7	9	7	38	

graduation course. However, for the students who do not intend to become an entrepreneur, is not fair to be penalised in grade due to topics outside the curriculum.

5. Feedback and learned lessons

The feedback considered the three classes of actors involved in the experiment: the instructors, the investors and the students. In each case, the impact of the experiment in the students is commented. In Learned Lessons, a partial answer to the feedback is given.

5.1 Instructors' feedback

Although very demanding, the instructors evaluated the experiment, an excellent opportunity to work, present activities and plan their classes by observing knowledge frontiers and necessities of other subjects, in order to reach a common goal.

The instructor of Principles of Economics reported an improvement of the students' participation, with more questions and involvement in class activities in the topic of microeconomics. The instructor of Environment and Sustainability observed better students' involvement with the cases presented in class, since they were motivated and concerned with the monitoring system under development.

5.2 Angel investors' feedback

The investors consider it very important to expose the students to situations in which they have to convince other professionals to finance their ideas, presenting the work previously done. They encouraged the interdisciplinary approach, which stimulates the students in activities related to entrepreneurship and innovation.

The investors raised some criticisms about the projects. One criticism regards the business plan presented by the teams. For this investor, the emphasis on the prototype building was higher than the business plan. In his opinion, this bias was understandable considering the team's formation, but it should be better balanced considering the proposal as a whole.

Another investor commented that many teams did not make a clear identification of the problem to be solved. For this investor, this question was vital to understand the proposed solution and the viability analysis. Another investor commented about the lack of research about similar solutions available in the market. For this investor, many teams could have had a better business plan and prototype if this research had been made. A third investor proposed that the presentation should have between 15 and 20 minutes, in this way the students would have a longer contact time could with the angel investors. He ended his comments with the observation that the students should improve its presentations.

5.3 Students' feedback

At the first edition, we asked who would give us feedback with their impressions about the experiment done. We had qualitative written feedback from four students. Some students presented their considerations and feedback in informal conversation. None of the students who gave their feedback considered the experiment a bad experience. However, some considered that the experiment should be ended, as it will be commented after. The students evaluated positively the necessity of the interdisciplinary approach in the engineering curriculum. In their opinion, the number of activities decreased, because the subjects worked in connection. And, at the same time, more meaning was given to different subjects. One student suggested the development of one year course to increase the interdisciplinary with other courses, aiming to form star-ups companies.

Many students complained about the amount of documentation required (documents review) and recommended its reduction, see Fig. 2. Following this line, one student commented that the approaches of System Engineering are too demanding to be applied in one semester project. This might give the false impression that the System Engineering's tolls are only a bureaucracy to overcome. The student suggested templates focusing on the product description, a subsystem division and fault analysis for the documentation process. A partial opposing opinion was given by another student. In his opinion, the follow-up provided by the instructors by means of reports and planning along the project development was very import for reducing the chance of project failures. The same student commented that the interaction among the courses should be improved. Because of this not improved interaction, the focus on many projects was on system engineering rather than an environment problem solution, reducing the interdisciplinary approach. He also suggested an industry-oriented problem solving, instead of a problem proposed by the students. This would motivate the students by reinforcing the contextualization and the study of actual cases in the area. Concerning the invited lectures, the student suggested lectures with an environmental approach, dealing with subjects like ISO14000, product's life cycle, and ambient monitoring and risk assessment.

In the first version, some students made some remarks about a pre-determined project. In their opinion, it would be better a team proposal rather than a specific project to all teams. Also, some criticisms were presented regarding the simplicity of the prototype to be developed. These students were eager for more complex systems. These weak points in the first edition were known since the beginning by the instructors, however, it was considered better to begin the interdisciplinary project with these restrictions and allow more flexibility in the second one, how it happened.

In the second edition, the students were asked to answer a questionnaire about the experiment. Forty-two (42) students answered the questionnaire. Table 3 presents students feedback to two question about the implementation of the experiment.

Table 4 shows that the students were divided in the experiment approval. Even though the interdisciplinary experiment planning was very carefully executed to accomplish the interdisciplinary goal, this feedback indicates that the interaction among the involved courses can be improved. The basic device kit had a major approval among the students.

Asked about the project requirements in the second edition, four (4) students considered them too much flexible, which let the team with many doubts to present a proposal. Twenty-seven (27) students considered them flexible, which allow the students to exercise their creativity. Six (6) students considered them not flexible enough, so it was not possible to present proposals aligned with Environment and Sustainability. Five (5) students answered with other comments, such as the difficulty to work with the sensors, lack of instructor support to work with the sensors. Among these five students, two pointed that the requirements were satisfactorily flexible.

There was some qualitative feedback also. Contrasting with one investor's opinion regarding the business plan, one student commented that the time spent specifying requirements and economics standards were too high. This time would be better used developing the prototype, and he added that the prototype purpose should not be restricted to environmental matters. Another criticism regards the emphasis given to the technical system development to the detriment of environment and sustainability related issues.

As it was commented in the first version, also in the second version some students of Computer Engineering, even though considering the interdisciplinary experiment valid, complained about the fact that this experiment happens in the last semester of the course. At this time, they are already involved with other activities, oftentimes external to the University. So, for them, this experience should be ended for undergraduates in the last semester.

5.4 Learned lessons

The formation of a teaching team is not a smooth process and some tension among the instructors, regarding the emphasis on the subjects to be taught and the time that the students should spent on each activity, should be expected as a natural motivation of each instructor.

The angel investor participation is fundamental for the students. Their professional expertise and valuable comments highlight the importance of environment, sustainability and economics for electronic and computing engineers. The students view their comments as advices from a colleague who

Table 4. Students feedback about the experiment implementation

	Totally agree	**Agree**	**Partially disagree**	**Completely disagree**
The experiment had met the interdisciplinary proposal.	7	15	11	9
	Yes		No	
The basic device kit is adequate	34		8	

dealt with similar problems along their professional life. The focus on the project and its engineering system related activities should be better balanced. Many students' criticism pointed out this problem. However, one have to consider that engineers in general do not like documentation or reports and these criticisms have a bias natural to their academic expectations [30].

Regarding the presentation to the angels' investors. It would be very appropriate to extend presentation time of each student team to 15 or 20 minutes. However, this would lead the presentation to investor's to be accomplished in more than one day of work, also considering the investors comments for each student team.

The interdisciplinary issue was viewed positively in the students' opinion and should be reinforced. This might be achieved by a reduction in the regular classes of Principles of Economics with oriented activities regarding the project business plan.

6. Conclusion

The necessary assignments for an interdisciplinary approach were covered. The students developed a technical system project related to environment and sustainability using electronic and computer engineering skills, worked with review documentation used in industry, studied the market situation to launch the developed product in the market and presented their prototype to potential investors.

In general, engineering students like to be involved with current issues problems in which they need to use their creativity and technical knowledge. On the other hand, there is a world tendency to foment entrepreneurship among engineering students. However, even though it is a tendency, the activities related such as study the niche market possibilities, develop a business plan, are not very practiced in the engineering courses. A very positive feature of this experiment is the joining of two aspects, technical and entrepreneurial, in an interdisciplinary proposal during the graduation engineering course.

It is noteworthy the tendency to foment entrepreneurship among engineering students by the fact that the angels, experienced engineers, were more excited about the business plan than the prototype development. Also, the students value the experience to present their project to an angels bank. However, related to the evaluation of students by the angels' bank, the possibility for this evaluation do not be reflected on grades, since the angels sometimes ask questions outside the curriculum, but in rewards (award plaques or cash reward) is a very adequate change to be implemented.

In the first edition of the experiment, the students complained that it would be better if they could request devices outside the basic kit. In the second edition, the number of devices available for the students were bigger than in the first edition and they had the opportunity to request or to buy devices to their specific project. However, just three teams asked for specific devices. With only two editions performed, it is not conclusive if the increase in the number of devices from the first to the second edition was sufficient to cover the need in the general project proposals or, as the possibility to ask to buy devices is a new possibility to the students, with which they were not familiarized, they did not access the opportunity.

The process of creating a multidisciplinary experiment, the lessons learned by the implementation process and the feedback of the involved actors, described in this paper, seems to be significant data to a world in which young engineers entrepreneurs are valued as job creating possibilities.

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