STUDENTS' ENGAGEMENT IN THE IMPLEMENTATION OF RESULTS OBTAINED IN CAPSTONE DESIGN COURSES: A PRELIMINARY MODEL FOR DETAILED DESIGN AND GO-TO-MARKET ACTIVITIES

Eduardo de Senzi ZANCUL[1], Paulo BLIKSTEIN[2], Luiz Fernando Cardoso dos Santos DURÃO[1] and Alexandre Machado ROCHA[1]
[1]University of Sao Paulo, Polytechnic School of Engineering, Brazil
[2]Stanford University, Graduate School of Education, USA

ABSTRACT
Capstone design courses aim to provide students with real-life, complex, and complete design experiences. Students typically work in teams to design solutions for problems presented by partners. Capstone design courses have been widely disseminated with positive results, and there is a sturdy body of literature on the subject. However, it has been a challenge to follow through with the proposed designs in order to achieve actual implementation, since this would require extra involvement of students after the capstone course has ended. As a result, for the students, in most cases, despite their design experience, they lack relevant steps and closure. Considering these limitations, an optional extracurricular pilot program was defined to engage students in design activities taking place after a capstone design course has ended. The objective of this paper is to describe the experience with the program and to present a preliminary model for program deployment in other settings. The program was carried out in one and a half years, starting in 2014, and initially targeted 25 students. Results indicate that the most important reasons for joining the program are extending the practice and knowledge related to the design approach, personal satisfaction, and learning technical skills. The pilot program resulted in the identification of two main phases – detailed design and go-to-market – and different project paths related to portfolio management. A list of activities performed by the students in each phase is provided. Albeit limited, results might be meaningful for future related initiatives.

Keywords: Capstone design courses, design implementation, detailed design.

1 INTRODUCTION

The main aim of capstone design courses is to provide students with a significant real-life design experience [1]. Additionally, capstone design courses can generate valuable results for corporate partners involved in project definition, mentoring, and sponsorship [2]. However, empirical evidence shows that the implementation of the results by partners has still been limited in many universities and settings. Reasons for the limited implementation include the need to further detail the project and to provide additional evidence of technical and commercial feasibility. When the design progresses, it usually advances without the involvement of students. Generally, there is limited opportunity for the students to participate in the "follow-up design refinements, implementation efforts, or commercialization" [3], since these activities are usually conducted by the partners after the capstone course has ended and the academic results have been delivered. Thus, for the students, "the experience does not usually lead to a successful closure of the design experience" [3].

Considering these limitations, an extracurricular optional pilot program was defined to engage students in activities taking place after a capstone design course had ended. The main purpose of the program was to create an additional learning experience. The hypothesis was that the experience would include enhanced real-life project character, seeing that progressing towards product launch would require an increased partner involvement and decisions with a real business impact.

The pilot program was executed with a single partner – a major hospital – and involved a four-project portfolio – two medical devices, a software app, and a gadget for patients. After the capstone design course, the students originally involved in the projects during the course were invited to join the detailed design phase as an extracurricular activity. During this phase, detailed design was conducted in parallel with extensive prototyping and testing. Activities were supported and sponsored by the partner.

The objective of this paper is to describe the experience with the pilot program and to present a preliminary model for program deployment in other settings. We sought to answer two research questions: Which activities do students perform during the detailed design after a capstone design project? What are the main reasons for students to engage in or to quit the extracurricular program?

The paper is structured as follows: the next section summarizes the literature on capstone design courses. Section 3 details the research method. Section 4 presents the data analyses and the discussion of the results. Finally, section 5 draws the conclusions and presents suggestions for future research.

2 CAPSTONE DESIGN COURSES

Capstone design courses have been widely disseminated aiming to provide senior level students with a significant design experience [4]. In this type of course, students usually work in teams to apply their previous knowledge and to tackle "real world", complex, and open-ended problems. The outcome is a proposed design solution, which, in many cases, is materialized in a final prototype [1], [5], [6].

Since the 1990s, there has been an increasingly relevant body of literature in the area. A fundamental survey on more than 170 North American engineering schools presented an overview of the main characteristics of capstone design courses. Some of the attributes analyzed are course duration, students' team size, degree of faculty involvement, and the industry involvement as external partners and sponsors [7]. An extensive literature review showed that although "the individual structures of capstone design courses are extremely diverse, the objective of nearly all such courses is to provide students with a real-life engineering design experience"[8].

More recent research advances focus on and compare specific course characteristics. Comparative research analyzed the impacts of course duration and team size on students' outcomes, comparing a one-semester to a two-semester offering [2]. Course comparison has also been applied to compare students' achievements as a result of monodisciplinary and multidisciplinary teams [9]. Courses can involve students from one single university or a team of globally distributed students [10].

In summary, many aspects of capstone design courses have already been widely discussed in the literature. There has been significant experience in course application over the last twenty years. However, despite the empirical evidence of the students' innovative and high quality course deliverables, it has been a challenge to follow through with the actual implementation of the proposed designs, because this would typically require extra involvement of students after the capstone course ended [3]. Many relevant capstone courses end at the solution proposal stage and prototype presentation. With the termination of the academic course enrolment, students typically do not participate in follow-up activities that would be necessary to implement and to commercialize the proposed designs.

3 RESEARCH METHOD

The overall research approach is based on the definition, execution, systematic assessment, and description of a pilot program to engage students in detailed design and go-to-market activities after a capstone design course at the researched university.

The university follows a semester structure. Capstone design is a one-semester course. Students work in multidisciplinary teams of 6.1 students on average (std. dev.1.2). An average students' semester cohort is 6.3 (std. dev. 3.1), while the overall undergraduate duration is ten semesters for engineering and for industrial design students, and eight semesters for business and economics majors.

The pilot program was executed with a single industry partner. The partner is a leading hospital located in the same city as the university. The hospital established an innovation department focused on prioritizing internal innovation demands, and on establishing partnerships to develop solutions that could later be adopted.

The pilot program duration was one and a half years, starting in the mid 2014. The first six months comprehended the capstone course for two projects, namely an oxygen flow measurement device and an app to manage the location and transportation of stretchers inside the hospital. After the capstone course, these two projects were selected for continuation. Students were invited to optionally join the detailed design phase as an extracurricular activity for an additional six-month period, initially. The partner sponsored the project continuation. Participating students earned a scholarship corresponding to a typical on-campus research support stipend for undergraduate students at the same university. The objective of the project continuation was to detail the design and to construct advanced prototypes for testing, to support IP protection as well as discussions with potential manufacturers and service companies that could license and provide the solutions to the hospital.

In the first semester of 2015, simultaneously with these two project continuations, a new capstone course occurred with two additional projects sponsored by the same hospital – a catheter cleaner and a glucometer for patients. In the mid 2015, the students involved in the two more recent projects were also invited to continue the project under the same conditions of the students in the previous semester.

Both capstone classes (second half of 2014 and first half of 2015) originally involved 25 students (out of the 98 enrolled), who were invited to follow through with the partnering hospital. Out of the 25 students, 19 decided to join and 6 quit just after finishing the capstone course. Reasons for joining were researched by means of an anonymous online questionnaire. Students were requested to rank ten reasons for having decided to continue engaged in the project. The reasons for quitting were discussed with the students in short interviews conducted by phone or in person. During the pilot program, the activities performed by the students in their projects were registered.

Based on the pilot program, a phase and activity model representing all the four product cases analyzed was derived. The model is structured in the detailed design and go-to-market phases. Decision points are mapped and alternative routes for each phase are pointed out, including the corresponding plan of activities for the students.

4 RESULTS AND DISCUSSION

The first result is the identification of different project paths during continuation. As expected, the partner company involvement increases with detailed design, and as decisions with business impact are made. As a result, typical portfolio management decisions follow, such as project continuation or termination. Figure 1 presents project progression and main decisions. The duration of the project for the oxygen flow measurement device was initially extended for six months. The extension involved reviewing the proposed solution to adopt a more efficient and more reliable alternative. It was identified that the design proposed during the capstone course was subject to failure and, therefore, it would not pass certification tests. After the first six months, the project was extended for an additional six months due to its potential benefits. In parallel, it entered the go-to-market phase, with the preparation and deposit of a patent, besides a first meeting with a company interested in the IP licensing to produce the product. The stretchers app evolved from a prototype to a fully functional system during the detailed design. The students were not able to perform complete debugging and operational performance improvement. However, despite the progress, the innovation management department of the partner decided to terminate the project because a more comprehensive IT solution including the functionalities was to be adopted by the hospital. The catheter cleaner project went faster than that of the oxygen equipment, as no major change in design solution was necessary. The last project status was the IP protection analysis. Finally, the glucometer project was interrupted just after the design capstone, due to the limited commercial potential, as an emerging commercial solution produced by a competitor was gaining force.

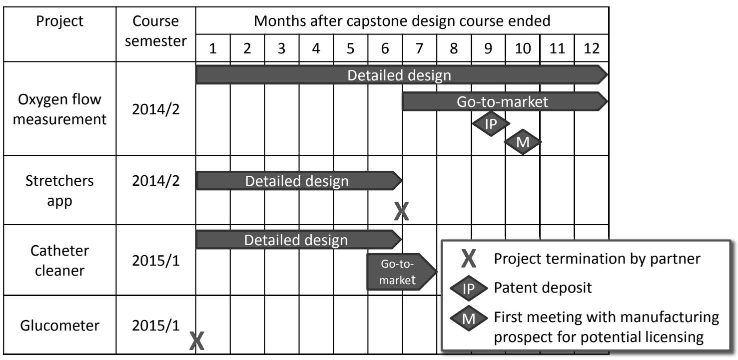

Figure 1. Continuation phases, milestones and duration

During the program, students were considered as a single class and all of them were able to continue to be engaged even after a project was terminated. Table 1 presents the activities performed by the students in each project.

Table 1. Activities performed

Project	Detailed design	Go-to-market
Oxygen flow measurement	Testing of alternative principles and solutions for the main function Selection of an alternative more efficient solution Detailed electronic design of a dedicated PCB Detailed mechanical design for fabricated parts Software programming Advanced prototyping	Patent search Competitors' analysis Support IP office for patent University and partner IP offices follow up during patent deposit Presentation of the solution to manufacturer for potential licensing
Stretchers app	App programming – fully functional Advanced testing	
Catheter cleaner	Improved ergonomics and aesthetics Designing a new improved mechanism fixation for cleaning material (subassembly) Prototyping in final size and fully functional	Patent search Competitors' analysis Support IP office for patent analysis

Figure 2 presents the product evolution related to the project phase for one selected example. The solution principle for the oxygen flow measurement device changed from the capstone course to the detailed design to consider rigid certification procedures and medical requirements, which students could identify during the tests and the extended data gathering.

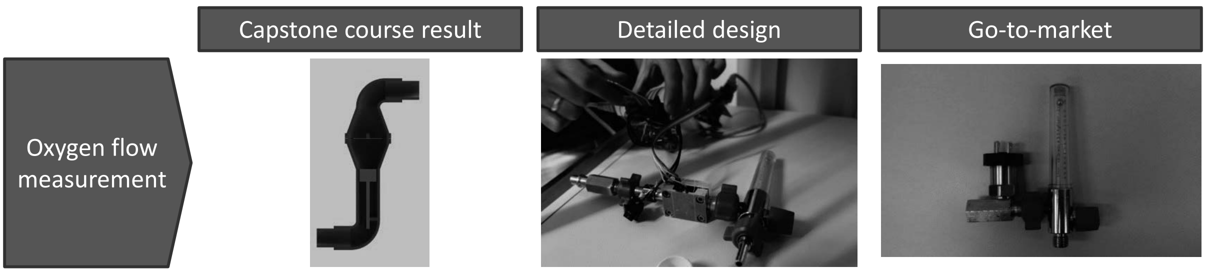

Figure 2. Product evolution

Students that decided to continue engaged in the project after the capstone course were requested to rank the reasons for joining in an online anonymous questionnaire. Table 2 presents the ranking, from the preferred reasons to the less important ones. The top three reasons are: 1. extending the practice and knowledge related to the design approach (referred to design thinking); 2. personal satisfaction; 3. technical skills learning. The scholarship and extending the relationship with the particular partner were considered less relevant for the students researched.

Table 2. Reasons for joining continuation – ranking – order from 1 to 10 (n=20 students)

Reasons for joining continuation	Mean	Variance
Acquiring deeper knowledge on the design approach (Design Thinking)	3.20	7.85
Personal satisfaction related to bringing the product to the market	3.25	3.78
Acquiring deeper technical skills	4.75	6.62
Participating in IP protection / co-author one patent	4.85	6.24
Consider the project for a potential own start-up initiative	5.25	6.72
Acquiring knowledge of business models (Canvas)	5.90	7.57
Getting access to other academic opportunities with the same faculty group	6.10	6.52
Continuing engaged in the same group of students	6.50	6.68
Scholarship	7.40	6.25
Increasing/Improving the relationship with the particular partner	7.80	5.64

Reasons for not joining immediately after the capstone course included the following, each cited by one single student: devoting time to internship, divergence with the group, not liking the medical devices area, graduated. Two students did not answer this question.
The engagement profile over time, including dropouts, is presented in Table 3. For both classes (2014 second semester and 2015 first semester), the engagement level in project continuation was high – 10 out of 13 students and 9 out of 12, respectively. This indicates that the model seems to have a relatively high appeal to the students, due to the reasons presented in Table 2. However, over time, drop out is also significant. Drop out was concentrated in the 2015 first semester class and in the initial months after continuation began. In order to complete the team, two additional students were admitted to the project during execution.

Table 3. Engagement profile over time

Project	Course semester	Original group size	Continued / did not continue	Student's quitting activity - # of months after capstone design course ended													Engaged at the end
				0	1	2	3	4	5	6	7	8	9	10	11	12	
Oxygen flow measurement	2014/2	7	6 / 1	1						1		1					4
Stretchers app	2014/2	6	4 / 2	2								1			1		2
Catheter cleaner	2015/1	6	5 / 1	1			2	2									1
Glucometer	2015/1	6	4 / 2	2			1	1	1								1
No project	x	2	2 / 0														2
TOTAL		27	21 / 6	6	0	0	3	3	1	1	0	2	0	0	1	0	10

The reasons for quitting were surveyed among students in individual interviews conducted mainly by phone. Reasons include: devoting more time to school (2 students), devoting time to internship (2 students), devoting time to other projects (2 students), travelling in an international exchange program (2 students), devoting time to one's own start-up (1 student), graduating (1 student), dropping out from the university (1 student).
As a synthesis of the pilot program, it was observed that a project may have different paths after the capstone design: immediate termination, detailed design and termination, detailed design followed by go-to-market. The detailed design, in turn, may follow the same design principle developed during the capstone course, or the solution may need to be reconsidered. Go-to-market may lead to IP protection and to negotiation to license IP. We did not experience a start-up creation stemming from the project in any of the four cases or any own production or service provision by the partner, as this would fall outside its core activities. Figure 3 presents a preliminary model for students' engagement in the implementation of the results obtained in capstone design courses.

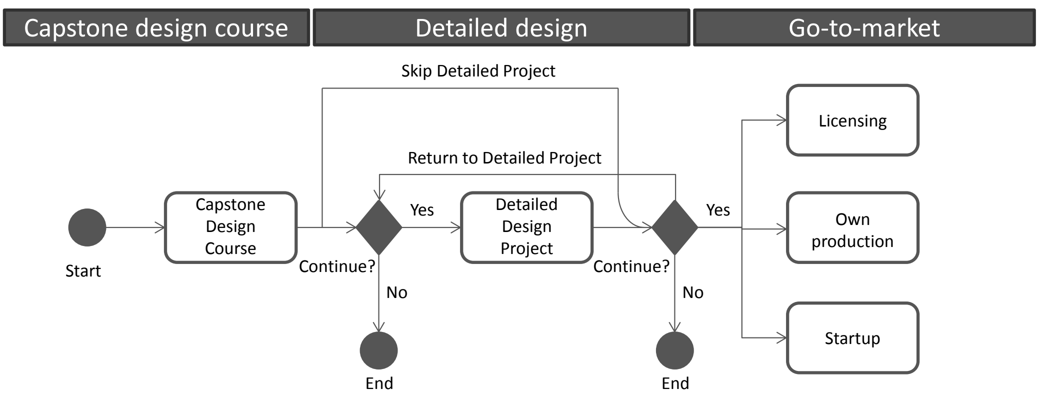

Figure 3. Preliminary model

A sample of activities that may be performed in each of the phases is provided in Table 1.

5 CONCLUSION

The pilot program proposed appeared to be an attractive extracurricular activity for the students – 19 out of 25 students (76%) joined the pilot program immediately after the design capstone course had finished. The most important reasons for joining included extending practice and knowledge related to the design approach (referred to design thinking), personal satisfaction, and learning technical skills.

However, dropout rates were also significant during the pilot. Approximately half of the students quit the program before it ended. This may be related to the fact that students were not enrolled in a specific course for the program and quitting had no major consequences. This may indicate that enrolling students in a particular course may be necessary to increase retention rates at least over the defined periods (quarter or half), which could facilitate the project planning and the results deliverable for the partner.

The pilot program resulted in the identification of two main phases – detailed design and go-to-market – and different project paths related to the portfolio management. The pilot also resulted in a list of activities performed by the students during the project extension for this particular case. Although the results are limited to the studied case, they may be helpful as a starting point for future related initiatives.

Further research suggestions include applying the model presented in different settings (e.g. universities, project types) and the analysis of students' perceptions of their commitment and learnings.

REFERENCES

[1] J. V Farr, M. A. Lee, R. A. Metro, and J. P. Sutton, Using a Systematic Engineering Design Process to Conduct Undergraduate Engineering Management Capstone Projects., *Journal of Enineering. Eduation.*,2001, 90(2),193–197.

[2] P. M. Griffin, S. O. Griffin, and D. C. Llewellyn, The Impact of Group Size and Project Duration on Capstone Design., *Journal of Enineering Education*, 2004, 93(3), pp. 185–193.

[3] B. Hyman, From capstone to cornerstone: A new paradigm for design education, *International. Journal of Enineering Education*, 2001, 17, pp. 416–420.

[4] M. Borrego, J. E. Froyd, and T. S. Hall, Diffusion of engineering education innovations: a survey of awareness and adoption rates in U.S. engineering departments, *Journal of Engineering Eduation*, 2010, 99(3), pp. 185–207.

[5] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, Engineering Design Thinking, Teaching, and Learning, *Journal of Engineering Education*, 2005, 94(1) pp. 103–120.

[6] J. a Marin, J. E. Armstrong, and J. L. Kays, Elements of an Optimal Capstone Design Experience, *Jounal of Engineering Education*, 1999, 88(1), pp. 19–22.

[7] R. H. Todd, S. P. Magleby, C. D. Sorensen, B. R. Swan, and D. K. Anthony, A survey of capstone engineering courses in North America, *Journal of Engineering Education*, 1995, 84(2), pp. 165–174.

[8] A. J. Dutson, R. H. Todd, S. P. Magleby, and C. D. Sorensen, A review of literature on teaching engineering design through project-oriented capstone courses, *Journal of Engineering Education*, 1997, 86(1), pp. 17–28.

[9] N. Hotaling, B. Fasse, L. F. Bost, C. D. Hermann, and C. R. Forest, A quantitative analysis of the effects of a multidisciplinary engineering capstone design course, *Journal of Engineering Education*, 2012,101(4), pp. 630–656.

[10] T. Carleton and L. Leifer, Stanford's ME310 Course as an Evolution of Engineering Design. In *Proceedings of the 19th CIRP Design Conference – Competitive Design*, Cranfield University, March 2009, pp. 547–554.