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ENGINEERING DESIGN EDUCATION IN TIME-SENSITIVE ENVIRONMENTS

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Abstract

The engineering design education has been undergoing reform for more than half a century. It was marginalized in the second half of the twentieth century mostly due to the proliferation of sciences and mathematics in engineering programs. Then, engineering design was restored through capstone projects as well as freshmen-level design required courses, after the outcome-based accreditation emerged. Due to the limited time of these design courses, students often end up rushing towards demonstrating a working prototype before the end of the course, and because of that, end up missing several important elements in process of prototyping. There is a new trend to build a 'design spine' throughout the engineering program as means of reform. We'd like to explore the impact of entrepreneurship on engineering design education because of its efficiency in solving time-sensitive problems through means such as rapid prototyping, lean startup, and customer discovery iteration. We used the course Technology Entrepreneurship at the University of Ottawa to test the design skills of the students who took it. We demonstrate positive results and discuss the possible contributing factors.

Keywords: Entrepreneurship, Design education, Design methodology, Design methods, Lean design

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1 INTRODUCTION

Technology is rapidly changing in a way that it is impacting engineering education. The average lifespan of technologies in some engineering fields are as short as a few years. By the time a technology is standardized, commercialized, introduced in textbooks, and the students who learnt it graduate, the technology would be already on its way to become obsolete. The gap between undergraduate students in engineering programs such as computer, electrical, electronics and telecommunications and the cutting-edge technologies in the related fields, such as mobile communication, cloud computing and artificial intelligence, is rapidly evolving.

1.1 Purpose of Research

We believe that the integration of entrepreneurship with design engineering is an imperative design philosophy that deserves a special emphasis within the engineering curriculum. The purpose of design engineering is to effectively and efficiently develop innovative products or services that appropriately respond to new user needs (i.e. adapt to change). Technological entrepreneurship – or even intrapreneurship - aims at teaching engineers to be better agents of change, either within existing organizations or through new ventures. Entrepreneurship is relevant to all engineering disciplines and its integration with design engineering will help ensure that engineers graduate with an ability of developing products that are responsive to change.

1.2 Paper Outline

The outline of the paper is as follows: Section 2 gives a brief history of design as a process. Section 3 describes our experience of teaching and assessing technology entrepreneurship as a method of teaching engineering design. Section 4 shows the results of our research. Sections 5 and 6 are for the discussion and conclusion.

2 ENGINEERING DESIGN AS A PROCESS

Although most engineering schools now have a capstone design project and perhaps some design elements in freshmen years, the gap in design is still a concern for many. A longitudinal study found that the confidence of engineering student in design deteriorates between the end of the first-year and beginning of the senior year (Kotys-Schwartz et al., 2010).

Due to the complexity of engineering design education, assessing it per the outcomes only may not be the best approach. A shift in mentality has been moving towards providing students with a continuous design thinking environment throughout the program. The earliest attempt of teaching design as a process this was by including a design requirement in every semester of the four years, as was done in Ramon University (Newell et al., 1999). However, that wasn't practical for several considerations such as course load, quality and feasibility of projects, and the reliability of the design assessment tools used. Recently, the shift has been directed towards creating a 'design spine' throughout the engineering program (Frank et al., 2011; Sheppard et al., 2008). However, most schools that are doing the spine are focusing on design in the classroom or for big clients. Our approach is to also build a design spine, but with a focus for entrepreneurship, that extends to extracurricular methods. We believe that teaching entrepreneurship to engineering students can be an effective path to deal with design in time sensitive environments.

3 SURVEY DESIGN

The research began as an exploratory study on the general impact of entrepreneurship on engineering education, the course Technology Entrepreneurship – which is now being offered for the seventh cohort – was described in an earlier publication (Jarrar and Anis, 2016). Our premise was that there were too many complex and unknown variables ahead that it would be futile to run an experimental study with an unclear hypothesis or set a control group without knowing all major contributing factors. Therefore, it was best to carry the study qualitatively. However, to do that, we had to verify that we took proper survey design considerations.

3.1 Research Questions

We formulated our research guiding questions to be the following:
Is teaching entrepreneurship an effective method in teaching engineering design? How do the engineering students who took an entrepreneurship course offered by faculty of engineering view the engineering design learning elements in this course?

3.2 Research Methodology

We used a mixed research methodology in this survey. In the quantitative part: we used a post-test analysis by providing students with an optional 60-question Likert-scale survey after they have completed the course. In the qualitative part, we combined open-ended survey questions with observational analysis of student progress and meta-analysis of student design assignment. While we uphold the academic view that research questions should derive the methodology and the method, not the other way around (Creswell, 2014), current engineering education research is lacking diversity in methodology and methods, with a bias towards qualitative methodology and statistical analysis as a method (Borrego et al., 2009).

3.3 Design Considerations

All survey questions were kept optional to increase validity of the answers, as participants were reminded on the top of every page of the survey that they could skip any answer they did not feel comfortable to answer. We also chose to restrict the survey on a post-test method to avoid ethical dilemma or potential implicit feeling of coercion during the semester. No student was asked or told about the survey during the course session, so that no student would think that participating in the survey might give them better grades in the course. Also, it was stated to the students on the survey front page that the survey was voluntary, and that they could stop at any time, and skip any questions. Most importantly, participants were told there would be no awards, gift cards or draws of any sort for participation. The survey was designed to not exceed 15 minutes in the worst-case scenario.
All questions were written in a neutral tone that avoids bias towards a specific answer. In every set of questions, one question was written as a negating statement such that participants would have to disagree with that statement for it to be considered a positive response. This technique was used to filter out participants who were not attentive in reading, or rushed through the page by clicking the same answer to all questions. For example, had a student agreed with all the statements in a page without reading, this question would show that they were not reading the questions, and hence their answer would be disqualified from our analysis. All these considerations were taken to ensure a higher confidence in the credibility of the participants.
To keep the survey within a reasonable time frame, we relied primarily on Likert scale questions. However, since scale questions tend to not give deep insight into the opinion of the participants, we adjusted the survey such that if a participant answers any question with a rating below neutral on a Strongly Agree to Strongly Disagree (SA-SD) scale question, they would get an open-ended question asking for more details on why the experience was negative. If the participant answers this question with over 50 characters, an additional question pops up asking if they could give an example of how this course could be taught differently to make that experience positive. The reason why we made these questions hidden by default and only show when prompted is to prevent the survey from appearing cluttered with so many questions and hence make people less willing to participate. More questions may also push some people to answer negatively. Overall, we found many the students responsive, and written thoughtful feedback, with suggestions to improvement, even when their response was negative.

4 RESULTS

The survey was sent to over 320 students who have taken this course in the past four years, and received a 30% complete response rate. The average response time was a little over 8 minutes. While the response rate is not high, the measures we included in Design Considerations gave us confidence not only that this is a representative sample, but also increased the validity of the responses as well. Among the questions asked there were ten statements regarding how the entrepreneurship course has impacted their engineering design thinking and skills. Students were given four choices to answer: significantly helped (in this discussion we denote ‘gh’), somewhat helped (‘sh’), helped a little (‘lh’) and did not help at all (‘nh’). All these questions were optional and so students were also able to skip a question if they did not want to answer 'na'. The summative column ∑ we added below indicates the percentage of students who reported they found this course to provide help to their engineering design thinking. Table 1 shows the response rates of the students.

Table 1. Survey results - Design questions

Statement	gh	sh	lh	∑	nh	na
Better understand engineering design principles	50%	25%	19%	94%	6%	0%
Gain experience with open-minded problems	56%	29%	15%	100%	0%	0%
Generate creative ideas (e.g. brainstorming)	56%	38%	6%	100%	0%	0%
Employ sustainability concepts into design	40%	40%	13%	93%	7%	0%
Properly document the design process	53%	27%	13%	93%	7%	0%
Accrediting the previous work of others properly	47%	33%	14%	93%	7%	0%
Ability to evaluate your own design	67%	20%	13%	100%	0%	0%
Ability to design with a group with different skills	73%	20%	7%	100%	0%	0%
Integrate economic aspects to the design	67%	27%	7%	100%	0%	0%
Learn to acquire and incorporate additional knowledge on your own	73%	20%	7%	100%	0%	0%

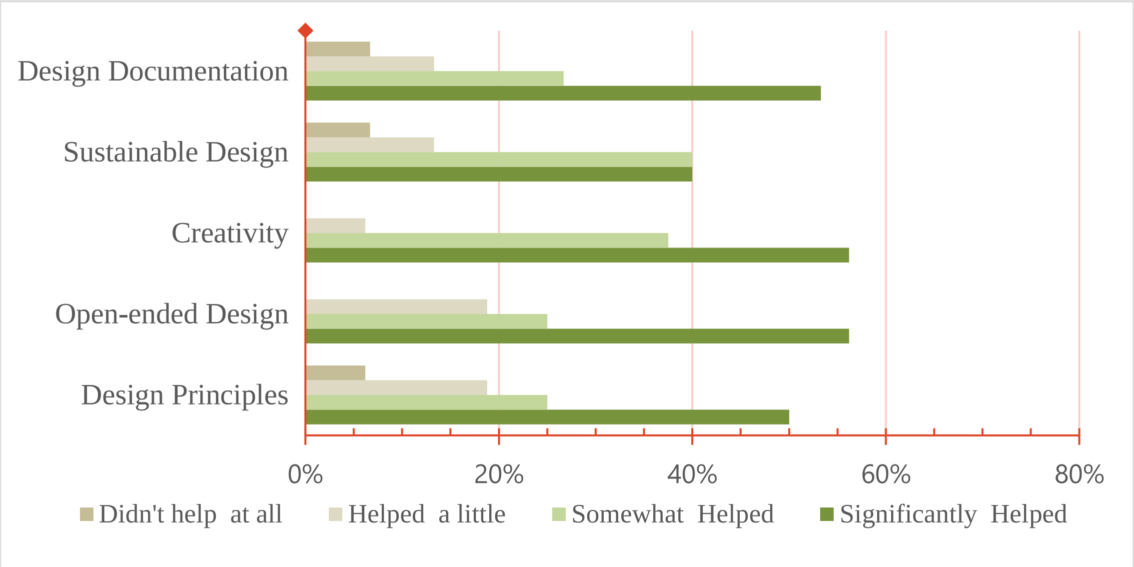

Figure 1. Survey results for first five design questions

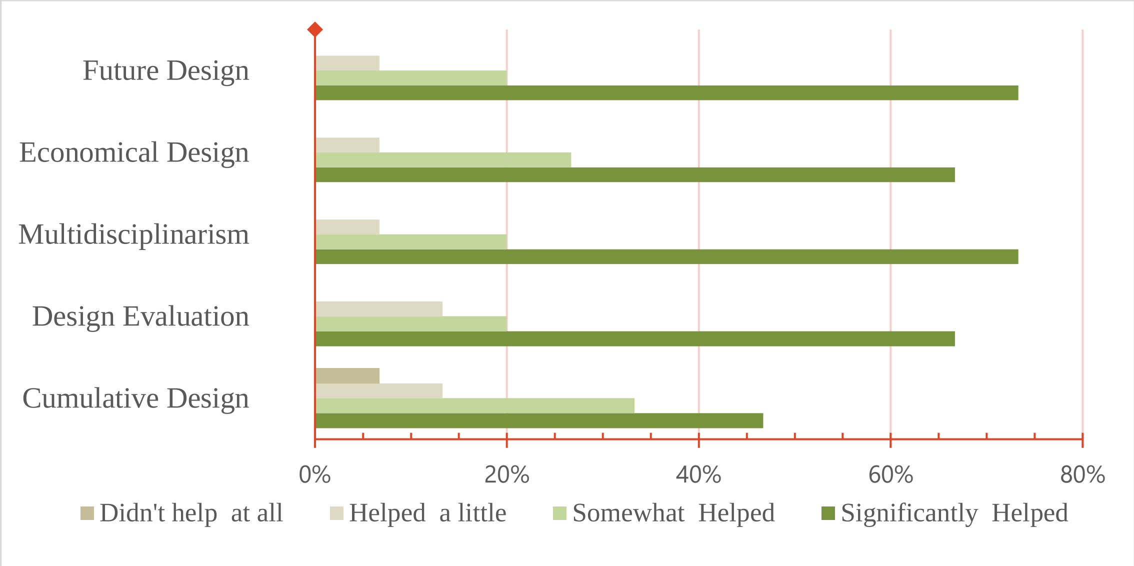

Figure 2. Survey results for the second five design questions

5 DISCUSSION

The survey showed a high increase in students confident and efficacy about ten design skills (Figures 1 and 2) after taking that course. In an open-ended question about what they thought about the course, numerous students elaborated that the course had a better impact on their design skills than the other courses they have taken during their university education, including those who were doing a second undergraduate degree or a master's degree.

There are few major reasons why we believe this improvement happened:

5.1 Customer-Discovery Design Iterations

The course includes six weeks of customer discovery. Each week, students survey 10-15 potential customers during which they demonstrate the idea (in following weeks: concept or prototype), give a questionnaire, get feedback and reiterate in the following week. The iteration with customers in the design process is something profoundly advocated for in entrepreneurship movements, and is usually absent in engineering product design and development processes. While normal engineering design process is iterative in the back-end, especially between the design and verification steps, these customer-discovery iterations bring the iterative approach to the front-end of design, where customer needs and product requirements are usually developed. Not only we have found that it reduces ambiguity and delay in later design steps, but also significantly improved students' communication and teamwork skills as well. While this method adds more time on the front end of the design, it can save significant delays that may arise in the back-end of the design process, and reduce the surprise element of coming up with a final product that does not meet customer's needs or expectations. Hence, this process can be more effective in time-sensitive environments than the traditional design process. Using this approach, any mistake or misunderstanding in the conceptualization phase (the customer need identification) can be detected and reiterated quickly. While in a traditional product design process (Figure 3), this would not be detected until the later stages of implementation.

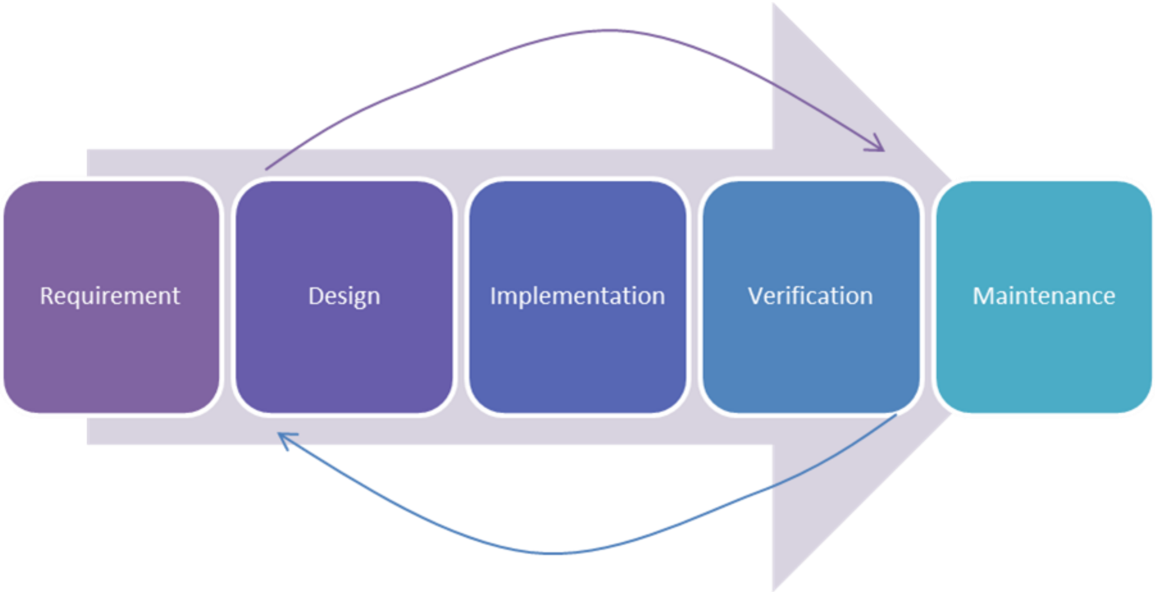

Figure 3. Traditional product design process where iteration takes place in the design and verification phases

5.2 Non-linear Design Process

Students only have six weeks to do five iterations, usually with eight or more milestones. In business model design and validation, students were encouraged to distribute and pipeline their design process instead of following a linear approach. In the first cohorts of the course, the students validated their business model with the customers in a consequential approach, starting with the value proposition in the first week, then customer segment in the second, then channels, then customer relationships, etc. If students reached the fifth week and discovered that the value proposition needs to be reiterated, they would get confused and the progress halts. Later, students were encouraged to split the work and test multiple assumptions at once in parallel and build upon them, then reiterate with a stress-test. This way the team would test, for example, the value proposition and the channels in the first week, the customer segments and the customer relationships in the second week, etc, then they would re-test the value proposition and customer segments again in the later weeks when their prototype is more matured. This resulted in a more effective feedback process and students had better insight on product placement (Figure 4). We have observed that students learned from this process to copy the same iterative process into their product prototyping; i.e. they breakdown the prototyping to modules and each works on optimizing their part locally, without specific instructions to do so.

5.3 Makerspace

Students are encouraged to use the makerspace outside class time for prototyping. The Makerspace at University of Ottawa is open six days a week and offers state of the art prototyping tools and equipment. It is a safe haven for design and innovation. A study was conducted on the makerspace users at the University of Ottawa and observed that 40% of engineering students who are introduced to the makerspace through a course for the first time, have continued to use the makerspace, some even after graduating, and about 23% said they were introduced to funding opportunities for their projects through the makerspace (Galaleldin et al., 2016). Such open innovation spaces are crucial to complete the entrepreneurial ecosystem and solidify the design spine in any engineering school, which would help establish a thriving and innovative community of practice.

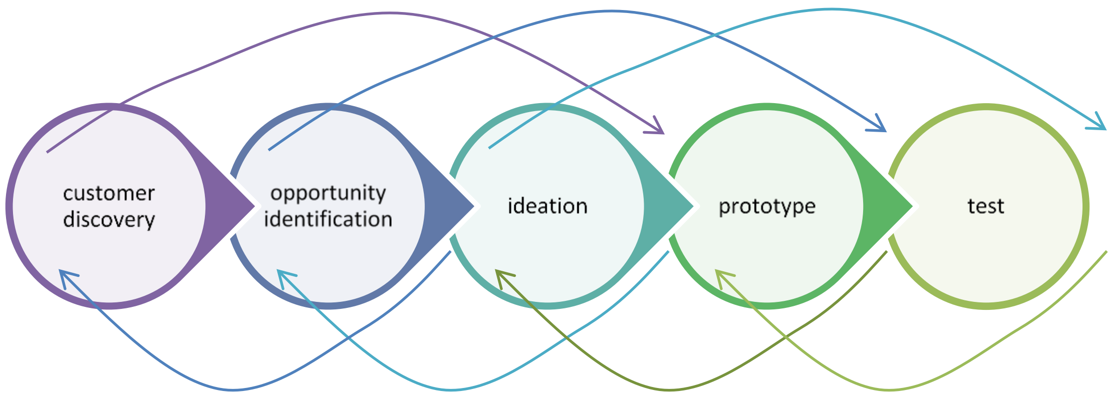

Figure 4. an entrepreneurial design process where iteration begins customers in the front-end of the design process

5.4 Competitions and Events

Since 2013, the majority of the participants in design competitions at the University of Ottawa have been alumni of the course Technology Entrepreneurship. Some of these competitions come with symbolic awards, others come with large cash support for ventures. In both cases, students who get involved in design days, competitions and networking events demonstrate high confidence and efficiency in their design skills, as evident from the frequency of participation and number of awards they achieve.

6 CONCLUSION

We have surveyed the main themes of engineering design education over the past seventy years. Engineering design education is still developing in both its pedagogy and assessment. We demonstrated how teaching engineering design in a time sensitive setting through the course Technology Entrepreneurship at the University of Ottawa, open to all undergraduate and graduate engineering students, impacted the students' design skills. We conducted a survey to the students who completed the course and found a significant rise in students' confident and efficacy about their design skills. We observed qualitatively and analysed some of the reasons behind this positive response.

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