Lessons Learned from Teaching a Pilot Multidisciplinary Entrepreneurial 4th Year Capstone Design Course

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Abstract – *During the 2015/16 academic year, a pilot course at the University of Saskatchewan was offered to senior engineering students. The pilot course was meant to offer an entrepreneurial version of the standard 4th year capstone design course. It also created an opportunity for students to work with students from engineering disciplines other than their own. Two design groups, each consisting of four students, were formed. This paper describes the structure of the course, how the entrepreneurial content and multidisciplinary aspects were handled, and a variety of lessons that were learned that may be of value to other institutions considering similar ventures.*

The College's capstone design courses had the weightings of two regular 3-credit courses, running from the start of the Fall term to the end of the Winter term. The most fundamental differences between this course and the standard 4th year capstone course were i) the students identified their own design problem, and ii) they formed multidisciplinary teams to solve their problem. Both of these differences created significant challenges in terms of organizing and running the course. Students from Electrical Engineering, Computer Engineering, and Engineering Physics were full participants in the course. Students from Mechanical Engineering were given the opportunity to participate on a one course credit basis i.e. they still had to take the standard 4th year design course in addition to the entrepreneurial version.

Many lessons have been learned from the experience of developing and teaching this course. Issues that will be discussed in the paper include, but will not be limited to: integrating the different learning outcome needs of the different departments involved, managing the uncertainty of the design problems undertaken, integrating entrepreneurship into the design course, talking about design to students from different disciplines, managing "sub-contractor" students in capstone projects, evaluation, scheduling of classes, multidisciplinary supervision, client interaction and evaluation of student work, peer assessment, and student group dynamics.

Keywords: capstone, entrepreneurship, multidisciplinary, engineering design

1. INTRODUCTION

Not all engineering students aspire to a career in operations and production. Some want to be the next Elon Musk. They want to start an industry instead of joining one. An undergraduate engineering education offers a singular opportunity for such students to test those waters at minimal risk, if they are allowed to do so. Some schools, especially in the US, permit this experimentation through engineering coursework e.g. [1, 6]. But many do not. In such cases, some students try pursuing their entrepreneurial interests through extracurricular involvement in clubs or groups. This can bring many benefits, but it is also a lost opportunity when they cannot benefit from the mentorship of teachers who could otherwise help them realize their dreams. Moreover, this benign neglect can breed resentment towards the Engineering school that stood in the way of their dreams, instead of supporting them.

Lest we forget, the pursuit of technological innovation is one of the main reasons many students enter engineering [2]. Yet many schools do too little to build on this motivation. When innovation is encouraged among these students, enthusiasm and reduced attrition can result [5].

Training students to be competent and dependable in existing industries that are often governed by precedence and proven solutions is of indisputable importance. Indeed, many engineering students want that kind of training. But many also want to be trained to be competent innovators and creators of new industries. This is also of indisputable importance in any modern economy. However, the learning environments where these two employment trajectories can be fostered are very different, and the latter is not often found in Canadian universities as it requires adaptability and comfort with risk. Perhaps not coincidentally, these are qualities of entrepreneurs [10].

Two years ago, this author joined the College of Engineering at the University of Saskatchewan. During my first year, I was fortunate enough to sit-in on and/or co-supervise 4th year design projects in Mechanical, Electrical, Chemical, and Environmental Engineering, as well as Engineering Physics. I recommend this experience to any faculty member with a serious interest in engineering design, and administrators should facilitate this kind of experience wherever possible. The ways in which different

disciplines approach design is more different than many might imagine. We are siloed so quickly in our education, and then remain thus, especially in academia, that we lose track of those deep differences. We have much to learn from each other and the cross-pollination can be fruitful for ideation and collaboration [3].

It was these two influences, the lack of entrepreneurial support and the lack of multidisciplinary exposure in the curriculum, which inspired the creation of a pair of new courses this past year; GE 498.6 – Technological Innovation Capstone Design Project, and GE 498.3 – Technological Innovation Design Project. The primary objective of these courses was simple: create a capstone design course where students could come up with their own design problem, and then solve it. And the students could form multidisciplinary teams to carry out the project.

This paper describes how the first year of these courses went. It discusses how the courses came about, how they were planned, and how they ran. It describes some of the outcomes, as well as some of the observations of the instructor and the students who took part. This was a pilot offering of the courses. This was not a systematic study of how the first year went, no research ethics board clearance was secured, and only generalities are discussed as a result. This paper is an anecdotal narrative, but hopefully one that will be worth the read for any that may attempt similar courses at their home institutions. Certainly others have also started developing these kinds of courses [4, 7].

2. PROLOGUE

GE 498 did not have an easy birth. Letting students choose their own design problems was (is) difficult for some to accept. Reasonable concerns were raised over how the suitability of project topics would be determined. This lead to two of the hallmarks and "safety mechanisms" of the course concept: departmental sign-off and disciplinary co-supervision. Every student would have a disciplinary co-supervisor to provide support and ensure technical rigour, and their home departments would have to sign-off on the student's involvement in the course, plus the specifics of the proposed project.

While selling the idea of students "driving the (design) bus" was expected to be a challenge, an equal though unexpected challenge was that of implementing the idea of design groups that were multidisciplinary. All departments were supportive of the idea, just as long as their students didn't miss anything from their traditional 4th year capstone instruction. So the new elements of GE 498 would have to be additional elements as opposed to being replacement elements.

The traditional 4th year design capstone courses are called "495" courses at the U of S. Typically, industrial projects are lined up over the summer with clients, and students select/are assigned to projects in September. This model is not atypical of other institutions, nor is it discouraged in this paper. This "apprentice" capstone model is valuable and important. It serves to motivate many students, and the exposure to real-life clients is an important highlight for many. Every model has its weaknesses though, and the weaknesses of this model are projects that are sometimes artificial, mundane, and/or lacking in real design work. These are certainly not the shortcomings of an entrepreneurial capstone model. The entrepreneurial model has its very own set of weaknesses, which we will discuss later.

Ultimately, GE 498 got off the ground due to three main factors. The first one was that GE 498.6 would be a proxy for the 495 courses. In other words, students could take GE 498.6 instead of their home department's 495 course. Otherwise, students would not take GE 498 as a second year-long capstone would be overwhelming, and because many could not take it with limited elective flexibility.

The second main factor was that departments could "opt in" to GE 498 i.e. the GE 498 proposal did not go to a vote as to whether all 3rd year engineering students could take the course. Had it, GE 498 would have failed to launch. Instead, under an "opt-in" agreement, Engineering Physics and Electrical/Computer chose to support GE 498.6. The other programs did not, although Mechanical half opted-in as we'll see shortly. I considered this to be the minimum level of support necessary to start the course, and that decision was validated this past year.

The third critical factor was the decision to have departments sign-off on projects, to have disciplinary co-supervisors, and to have students attend their home department 495 lectures as well as GE 498 lectures. This gave comfort to the departments that their 498 students would be seeing the same instructional materials as all of their other students.

Two other factors were of some help. The first was a promise that only a maximum of 5 groups could be supported, as no department wanted to lose too many students to this course. The second was the involvement of clients/users in a final assessment. This mirrored current 495 practice and fit very well with the learning objectives of the 498 course.

With permission to launch, the next issue was recruitment. Emails were sent to 3rd year students and Electrical, Computer and Eng Phys classes were visited. One group formed in May. Another came together later in the summer. These students were self-selected, and they included some of the top students in their programs. Eight students took part in the first iteration of these courses. Collectively, they came from four different engineering disciplines.

3. COURSE STRUCTURE

The main learning outcomes of the GE 498 course were the development of skills in problem identification, and of an appreciation for the importance of the problem

definition phase in design. As well, I wanted students to successfully realize their latent potential for technological innovation.

Students were required to attend a one-hour GE 498 class each week, and a weekly supervisory meeting with me, over the full Fall and Winter terms. As needed, they would also meet with their disciplinary co-supervisors. As well, they were required to attend all 495 lectures in their own department (1 hr/wk). Students needed departmental permission to take the course, which involved a review of their proposed project, and they also had to identify (and secure the support of) a disciplinary co-supervisor.

Having familiarized myself with many of the different 495 courses the previous year, I was aware of the great diversity in 495 deliverables. A middle ground was sought, and it was accepted by the supporting departments. Over the course of the 4th year, students would have to deliver:

i) a project management plan,
ii) a problem definition proposal,
iii) an interim report, and presentation,
iv) a final report, and presentation,
v) a proof of concept or prototype,
vi) professional logbooks,
vii) reflection essays, and
viii) peer assessments.

Client evaluations would also have to be arranged. These were all part of the formal course grade evaluation.

In terms of the lecture content in the course, it was assumed that all students would arrive with a basic competency in engineering design. As such, we would build on this foundation. Apart from materials in direct support of deliverables, the main focus was placed on:

i) team building,
ii) problem definition,
iii) new ideation techniques,
iv) new ways to evaluate competing solutions,
v) intermediate and detailed design steps, and
vi) business start-up resources.

In addition to the weekly lectures and design team meetings, a series of guest lectures were arranged over the course of the Fall and Winter. These guest speakers were entrepreneurs, for the most part. Some were young. Some were old. Some were in the early days of their venture. Some had been through many ventures. Once the topics of the projects had been determined, I was able to find speakers that in many cases had some relation to the 498 projects.

As noted in the Introduction, Mechanical Engineering (ME) had a unique role in GE 498. ME wanted all of their students to do ME 495. But they also wanted to help GE 498 succeed, if possible. So they proposed an intermediate role for ME students. ME students could elect to take GE 498.3, a one course credit design elective. These students would support a core group of EE/EP students who required the assistance of a Mechanical engineer. In effect, they would be a sub-contractor to the EE/EP students. They would attend all the same GE 498 lectures, and most design meetings, but they would not have as many deliverables i.e. they did not have to do interim reports and presentations.

Ideally, students were to have been selected for this course in April/May so that they could start working on the project over the summer. In the Fall, the focus would be on refined problem definition and project management planning. By Christmas, a conceptual solution would be determined and the Winter term would focus on more detailed design work, with the implementation of a proof of concept model or a prototype. Departmental 495 presentations were starting to happen by early March, and the GE 498 students were expected to present in their home departments. As such, they had to have most of their technical work done by early March, even though they had until early April to submit their final design reports.

4. HOW IT ACTUALLY WENT

Ultimately, the first year of GE 498 was a great success. It was not looking that way at Christmas, but ironically that might have been a contributing factor to the positive final outcome. The strong finish was due in large part to the quality of the students and to the flexibility of timing of course deliverables. It was not "easy sailing" and it could have failed miserably otherwise. Changes described in the Epilogue will hopefully reduce the risk of failure in the future but here is what went well, what did not, and why.

The first challenge was a squandered summer. One group did not do much work, and the other did not come together until late in the summer. We began work in early September (weeks ahead of the 495 groups) but we were also going to spend a lot more time on problem definition. So in a certain sense, we were already "behind".

The next challenge was class scheduling. With students from four different programs, there were no times during the week between 9 am and 5 pm that worked for all. So we set up night classes. That actually worked very well, due to the next challenge.

Students from different programs differed in their level of design knowledge and skills, considerably. So a lot of review was required. In the end, we slipped into a model whereby Fall lectures were about 2 hrs long, and Winter lectures were no more than 1 hr. For those students with a stronger design background, they appreciated seeing the material from a new perspective, and with new elements that they hadn't seen before. It was also a chance to "deep dive" on certain concepts that had only been treated superficially up until then. For students that hadn't seen design theory for a while, it was a fast-paced review with advanced material intertwined with the basics.

Another early challenge was recruitment of co-supervisors. Not being recognized for their role by their department discouraged some from participating.

Once recruited, however, co-supervisors were not the challenge that they might have been. In the end, the students needed very little technical help. Co-supervisors assisted in evaluations of reports and presentations, but didn't need to do much else. Co-supervisors can play a vital support role in a course like GE 498, but the ship needs to be steered by one pair of hands. This was not an issue this year, but this may not always be the case in future projects. Careful selection of co-supervisors is important to ensure that these mentors do not overly dote on "their" students.

By September/October, the students were focused on defining their design problems. One group ultimately rejected their original concept and found a new one. This was a very stressful situation, but also a great learning opportunity. They had found a problem that they loved, instead of persisting with a solution for which they had had trouble finding a clear need. They had found clients/users for their new design problem, and that was a huge source of motivation for the rest of the project. As I have observed in other design groups, passion (from strong problem acceptance) is the most important step, followed closely by problem definition. This group was behind, to be sure, but they had clarity of vision now and they made up for lost time quickly. The other group had the opposite challenge. They knew approximately what they were doing very early on (during the summer) but were hamstrung by complacency. They did not achieve the same level of clarity around their problem until after the other group, ironically. The reason became clear and was quite enlightening. They had been too polite with each other i.e. they had never truly gotten into the "storming" phase of group dynamics. Once this became clear, the group truly engaged and moved forward rapidly, again with an all-important clarity of vision. They had never lacked the passion. They had simply lacked a coherence of their expectations and a clarity of their collective direction.

These various issues required some risky changes in scheduling and evaluation. In one case, extensions were granted as more time was required for any reasonable deliverable. In the other group's case, a failed deliverable served as a wake-up call for them, and for the instructor. The offer of redemption through resubmission was embraced and everyone rose to the challenge. Interim reports were not seen so much as summative evaluations as they were seen as formative ones. The learning outcomes required flexibility in order to be achieved. These delays were risky to all concerned as the final presentation deadlines were not going to be extended.

The Fall lectures which were longer, went well by all accounts. The guest speakers were very popular, and motivating. Indeed, only one or two students starting GE 498 could have been described as actively entrepreneurial. But by the end of the course, all of the students were eager to engage in every entrepreneurial opportunity they could find. And they did engage. They entered a variety of design contests, inspiring each other with their confidence and enthusiasm, and achievements. The cautiousness of September gave way to assertiveness and courage in March and April. The change was palpable.

One of the unexpected positives concerned final presentations. Each group presented to any department represented in their group, with the exception of the Mechanicals (because 498 was not a 495 proxy). One group had to present three times. The other presented twice. Their passion and enthusiasm for their own projects became evident to others, and to themselves. They had a project of their own choosing and they knew it. They had worked hard without external motivation, and it showed. By presenting to different audiences, the students quickly realized the importance of tailoring their message to a specific audience. We taped their GE 498 presentations and put them on YouTube so that clients/users who were not able to attend, could see their work and comment on it. This had multiple benefits, not the least of which was greater exposure and the ability of many friends and family to see their work.

Both groups produced working proof of concept models. However, both were rushed efforts, and there was broad appreciation that kicking into gear sooner would have allowed for more development of more functionality.

The role of the Mechanical students (the 498.3 "sub-contractors") also presented challenges. In one case, they didn't clearly know what it was they needed to design until just after Christmas. Their work was of a suitable scope, but the work timelines were highly compressed, and they were not convenient for the student given his other coursework exigencies. In the case of the other Mechanical student, he was integral to the group's work throughout the year with the result being that he put more work into the project than some 495 projects. In both cases, the students felt they were outsiders at times, and this was largely due to the course logistics. With their own deliverables, they weren't full participants in the group deliverables but they did work alone on their own reports. This was an unintentional negative outcome that will soon be remedied.

5. EPILOGUE: LESSONS LEARNED

A conventional 4th year design capstone has risks attached with it. The primary risk can be characterized as minimal or artificial design complexity. It can be very difficult to find great projects for everyone. As such, some projects often are not great. They may not be particularly challenging, interesting or important. The 498 model, on the other hand, has the opposite risks. Students make their projects challenging, interesting and important and in so doing, as happened this year, projects can easily "blow up". Students can put lots of time into investigating a problem,

only to discover that it isn't really one. Perhaps even worse, they can put in that time and discover a great problem, only to realize that they aren't the right people to solve it. In the case of the GE 498.3 students, they may not have a clear idea of what their contribution will be until after a conceptual solution has been chosen i.e. Christmas. These risks must be managed better than they were this year. It would be unfair to students to get midway through a course only to realize that there was no future in it.

However, it must be accepted that the risks associated with a relatively uncharacterized problem can never be fully eliminated. As such, flexibility in evaluations can be strategically helpful as it makes the evaluations subservient to the project and not the other way around.

One of the new elements that was introduced to the course was intensive peer evaluations at year-end. These proved to be very insightful. Students put solid efforts into them and approached them professionally. These revealed some dynamics that would have been good to know earlier. Christmas peer evaluations may be very helpful for project mentors in future iterations of the course.

It should also be noted that the season's excellent guest speakers were great motivators to the students. These should be considered integral parts of the course, and their relevancy to the projects being pursued should be a significant factor in selecting guests. They were frequent inspirations to many students, both within the course and beyond. In fact, younger students coming out to the guest speaker events were exposed to GE 498 in a very organic way, priming the pump for future years.

The initial introduction of information on design contests such as the Tech Venture Challenge [8] and the i3 Idea Challenge [9] was meant to provide a bit of variety and excitement. It certainly did that. Next year, there will be systematic exposure to a series of venture opportunities, with strong encouragement to take part. There are low barriers to participation in these events, with high potential pay-offs. They are exciting and they help develop vital networking skills.

In one of the reflection essays, a student made the case that the (conventional) design process is not the best design process for entrepreneurially oriented design, and that a more agile process would work better. This insight has motivated me to look at other design processes for future versions of GE 498. To me, this example best exemplified the idea of instructor and student as learning partners in this context. In the intimate atmosphere of the small course, inhibitions gradually fell and students were not afraid to say what they believed. While the students were in two teams, they gradually considered themselves to be one team. This common purpose was noted at the end of the course as a bonding agent.

Indeed, this year's two 498 design groups were very successful. They were both chosen to be among the best capstone design projects of the year, and one won an award for innovation. Both entered into a national/international biomedical design contest and made it into the finals. I used their design experiences as fodder for first year design instruction, and that helped build interest in their work among first years.

The most satisfying aspect of their achievement though, is how they felt about the learning outcomes of the course. At the end of the course, we held a debriefing session. The students enthusiastically spent hours talking about what they had learned, and many of the lessons were what one would have hoped for:

- being depended on as the only XX engineer in the group was scary at first, but very motivating and empowering later on
- talk to clients/users early and often
- there are lots of opportunities to tackle out there
- there are lots of bad/non problems out there
- critical thinking about criteria, constraints, functions and scope is important
- we were pushed out of our comfort zones
- design processes help reveal problems/opportunities
- you learn the limits of your discipline and your skills and knowledge
- you learn what other disciplines do well and how to depend on others
- take your time with the design process
- listen, don't be judgmental
- draw problems from the marketplace
- people aren't sold by numbers/calculations
- innovation is hard
- be confident in simple conceptual solutions
- know your team

Of special significance was the feedback from the students who had taken part in ME 495 as well as GE 498. They said that while the two courses were very different, they were both very valuable. They would not have wanted to have missed either course. This speaks to the value that both models embody.

6. FUTURE PROSPECTS

Success begets success. More groups have expressed interest in GE 498 for 2016/17, without any advertising. Word of mouth has been powerful. This has created a new challenge … selection of projects may be competitive.

It will definitely be more rigorous this year in the sense that acceptance into the course will not take place until late August. During the summer, the groups will be expected to deeply familiarize themselves with their chosen design problem. This will help ensure that they have identified a true problem. They will be mentored over the summer in this pursuit. This should effectively mitigate some risk around the issue of whether or not a design problem is real, and whether the students are capable of solving it.

GE 498.3 (Mech) students will be fully integrated into existing GE 498.6 deliverables next year. As such, there will be more deliverables for them to complete, but they'll only be doing a part of each of them so the volume should be about the same or less. Most importantly, they will feel like and be seen to be full members of their design teams.

Other programs are considering involvement in GE 498 but the original challenges remain prominent. As of yet, no new programs have joined. On the other hand, all of the programs from last year are staying involved.

As for this year's groups, they are both wanting to see their projects continue. One group will continue to pursue the project directly, to see it help the people they designed it for. The other group will hand theirs off to an extracurricular entrepreneurial design club, so that younger students can build on their work. At least three of the individual students are considering starting their own businesses, and two have been selected/accepted into venture challenge contests.

This year's students had their own suggestions for improvements to GE 498 next year. They included ideas like learning how to lead meetings, encouraging more interaction with clients earlier, working more business content into the course, facilitating multidisciplinary team formation, practicing pitches to non-engineering audiences, and aligning some deliverables with design competitions/contests. They also encouraged me to develop other courses that allowed for multidisciplinary interactions.

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