Improving engineering students' need finding abilities; a work in progress

Meagan Flus, University of Waterloo

Meagan Flus is a MASc student in the Department of Management Sciences at the University of Waterloo. Her current research area is engineering design education with specific interest in design cognition. Her future work will focus on the intersection of data and design.

Mr. Christopher Rennick, University of Waterloo

Mr. Christopher Rennick received his B.A.Sc., Honours Electrical Engineering in 2007 and his M.A.Sc. in Electrical Engineering in 2009, both from the University of Windsor, in Windsor, Ontario, Canada. Chris is currently a PhD student in Management Sciences at the University of Waterloo. Since 2010, he has been employed with the University of Waterloo, in Waterloo, Ontario, Canada as teaching staff.

Dr. Ada Hurst, University of Waterloo

Ada Hurst is a Continuing Lecturer in the Department of Management Sciences at the University of Waterloo. She has taught and coordinated the capstone design courses in the Management Engineering program since 2011. She also teaches courses in organizational theory, technology, and behaviour. Her research falls in the areas of design cognition and processes, engineering design education, and gender issues in STEM disciplines. She is interested in innovations in engineering design pedagogy, problem-based learning, and effective teamwork in student teams. After completing undergraduate studies in electrical engineering, she continued on to earn a Masters and then a doctoral degree in management sciences, all from the University of Waterloo.

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Abstract

Design theories, such as the popular design thinking approach, outline several stages of design, typically: needs assessment, problem definition, concept generation, implementation, and evaluation. While engineering students apply design methods, they rarely practice needs finding. All Canadian undergraduate engineering students participate in a capstone project in their fourth year. Engineering instructors at the University of Waterloo have identified a lack of opportunities for students to practice their need finding skills prior to fourth year. As a result, a set of need finding instructional activities were conducted in-class for one term. The objective of this research is to conduct evidence-based program improvement by identifying the teaching practices that improve need finding competencies in engineering graduates. More specifically, in this ongoing study, the authors explore how students identify, select, and justify their capstone project problem; and whether in-class instruction on needs identification and assessment improved capstone project outcomes.

To address these objectives, we employed a survey to measure the effects of in-class instruction on student need finding abilities. The survey was disseminated to students halfway through their capstone design project. We compared the need finding and problem identification strategies of those students who received need finding interventions to those who did not and found the intervention encouraged students to begin their projects earlier and engage in a more in-depth problem finding process. Since the introduction of the intervention, capstone instructors recognized the benefit of education on problem-finding which was confirmed by our study findings. As a result, need finding has been implemented into course curriculum. Future work can determine if the effects of need finding interventions improved overall capstone project quality. The results of this project will aid in the design of future interventions and engineering teaching practices.

1. Introduction

As mandated by requirements put forth by the Canadian Engineering Accreditation Board [1], all Canadian engineering students participate in a capstone design project in their fourth year. One predictor of the quality of the capstone project is in identifying a "good" problem to address in the design. Most models of the design cycle prescribe needs assessment to be the first stage. While engineering students work on design problems throughout the duration of their undergraduate education, prior to fourth year, the design problem to be solved is typically assigned to them. Therefore, students rarely practice the needs finding step. For many students, the capstone project is the first time they identify a need on their own, and many struggle with this critical step.

It has been identified that engineering student teams have strong concept generation, implementation and testing skills, but they lack in their need assessment skills [2]. Instead of following traditional problem finding practices, students tend to "reverse-engineer" their design problem from a chosen solution. Weaknesses in the beginning stages of the design process can negatively affect the quality of the final design [3]. As a result, in-class activities were developed to better educate third year engineering students at the University of Waterloo on problem identification prior to beginning their capstone projects. In this study, we consider these activities to be a set of interventions. These interventions were only conducted during one academic term and varied between disciplines. Due to the nature of when these interventions occurred and the co-op program at the University of Waterloo, we can compare student need finding abilities between those who received the interventions and those who did not. The purpose of this paper is to provide a preliminary evaluation of the effectiveness of the interventions.

2. Background and Motivation

Traditional design theories [4], including the very popular design thinking approach [5], prescribe the following stages of the design cycle: need assessment (or empathizing), problem definition, concept generation (or ideation), implementation (or prototyping), and verification/evaluation (or testing). The phases of the design process outline a methodology that encourages project success.

Before engineering students complete design projects, they are provided some instruction on design methods, including on how to refine a problem statement, iterate their design, and develop a solution. However, due to the focused learning outcomes of course-based projects, and the limited time available in courses, most existing design experiences at the University of Waterloo provide students with instructor-defined project topics. When this is the case, students do not have the opportunity to get meaningful experience in the needs assessment stage of the design thinking model. As a result, need finding tends to be one of the weaknesses identified in students. It is known that weaknesses in the beginning phases of a design negatively affect the outcome of the final project [3]. Therefore, there is motivation to address the gap that exists in engineering education in developing student problem finding skills.

Engineering students at the University of Waterloo typically engage in design activity in their first-year engineering concepts course, and sporadically in course projects in the second and third year, but their most significant design experience is in their senior capstone design project. This is 8-12 months long and designed to resemble real engineering practice. Capstone projects have become the gold standard opportunity for engineering students to practice necessary skills; they are also an accreditation requirement by the Canadian Engineering Accreditation Board [1]. Since the quality of capstone projects is a summative demonstration of numerous program outcomes, it is important for students to succeed in their capstone projects. As need finding has been identified as a weak competency in engineering students, it is critical to improve these skills in order to ensure success in the capstone projects. One way to do so is with targeted training for problem finding strategies. Currently at the University of Waterloo, there is no such comprehensive training in place, and instruction on the topic is piecemeal by program. One example of the programming offered is a unique opportunity for students to engage in need finding during an immersive remote co-op term [6]. It was found that these students engaged in more advanced problem finding than students without this opportunity. While there are some successful need finding educational opportunities such as this, they are not available to all students, nor scalable.

The overall goal of this project is to improve needs identification competencies in engineering graduates. The strategy for achieving this goal was to design a set of pilot interventions consisting of a sequence of in-class sessions with field experiences for third-year engineering students.

The interventions of interest in this study varied slightly between the classes in order to better align with program learning outcomes, disciplinary differences, and logistical considerations. Nevertheless, the foundational structure of the interventions was similar. The in-class interventions were conducted on campus for three third-year engineering classes (MTE, ME, and ECE) from different disciplines during Winter 2019. They proceeded as follows:

1. All groups (MTE, ME, ECE) received a lecture on identifying a good problem. The session introduced structured ways of thinking about needs assessment and project identification through an adapted entrepreneurship framework [7]. The lecture taught problem-centric design with an emphasis on choosing a market, identifying relevant problems, and developing a solution aligned with the competencies of the group.
2. All groups (MTE, ME, ECE) also participated in a field experience to the fourth-year capstone symposia. These are public events in which engineering students present their final designs at the conclusion of their capstone design projects. Visiting the symposia was intended to provide the third-year students with an opportunity to practice applying the need finding strategies by looking critically at the work of their older peers in the program.
3. Two classes (MTE, ME) received an additional workshop on problem finding.
4. One class (MTE) was required to write a reflection on the field experience.

This paper presents the first steps in evaluating the efficacy of the interventions. To perform this evaluation, two research questions were posed:

1. *How do students identify, select, and justify their capstone design project problem statement, and are there structural differences in how students who received the intervention perform this step, versus other students?*
2. *Were the interventions helpful in teaching students about needs identification?*

This paper specifically looks at student **perceptions** of their design methods and the helpfulness of the interventions. A future, more elaborate, study is needed to evaluate the effectiveness of the interventions in improving need finding abilities.

3. Methodology

The University of Waterloo has mandatory co-operative work terms for all engineering undergraduate students. To graduate, students must complete five 4-month work terms in industry. Due to the nature of the co-op system, when students enter their program directly upon admission they are divided into cohorts according to their co-op stream, and stay with their cohort for their entire undergraduate degree. For most programs, there are two cohorts labelled 4-stream (students who enter their first work term after 4 months), and 8-stream (for students who enter their first work term after 8 months).

The interventions described in this paper were introduced during the Winter 2019 term for students in the second term of their third year (3B). As such, for each class, only one of the two cohorts of students were on campus and received the intervention. The natural division between cohorts presented an opportunity to study the effectiveness of the teaching interventions and compare them between experimental (those on academic term during Winter 2019) and control groups (those in a co-op work term during Winter 2019).

This study employed a survey methodology with the intention to compare the results between students who received the intervention and those who did not. In order to best determine the effectiveness of the interventions in helping students with their need finding processes, the survey was not employed until students had been working on their capstone projects for 3-4 months. The purpose of the survey was to capture a description of their capstone project topic, how they identified and refined this problem, and individual measures of the helpfulness of the interventions. Some key questions included:

1. *How did you find your [capstone design project] problem?*
2. *What methods did you use to gather information to better understand the problem?*
3. *How helpful was each of the following interventions in identifying a problem for you [capstone design project]?*

The first question was a free text, open-ended question. The researchers attempted to categorize the responses post-survey, instead of providing the students with options. This method allowed researchers to determine if there were natural patterns in the methods students used. The second question provided a list of options, of which students could select more than one, to grasp an understanding of the secondary data collection completed by students. The final question was scored on a Likert scale from 1 to 4, with 1 being “not at all helpful” and 4 being “very helpful” and students provided written text rationale for their ratings. The survey was filled in by individual student participants, and their responses could be aggregated by their capstone project groups.

4. Results

At the time of writing, the survey has 68 responses from fourth-year students across 3 engineering disciplines, representing 37 total capstone groups. Of the 68 respondents, 28 formed their capstone group during their final term of third year (3B), and 35 during the first term of their fourth year (4A). Every respondent had a project topic at the time of sample, with majority of groups picking a project topic during 4A (82%), while the remaining students selected their topic in 3B (18%). Individual responses were aggregated according to their capstone groups. The latter were categorized based on whether they were part of the control group or the intervention group. Of the 68 individual responses, only 15 (representing 10 capstone groups) had received the intervention.

From the survey responses, we identified six methods students had used to need find. Table 1 provides descriptions of each method and their distribution across the control and intervention groups.

Problem Identification Method	Description	Example	Frequency (teams)	
			Control Group	Intervention Group
Experience	The team encountered the problem during an experience.	"Through previous co-op experience" (Respondent 29)	13	4
Idea suggestion	The problem was suggested to the team by an external source.	"A professor suggested the basic idea, our team took it and thought about a better solution" (Respondent 26)	6	1
Discussion	The team encountered the problem in discussions with an external source.	"In one of the nanotoxicology courses the need for non-toxic flame retardants was mentioned. It was brought to my attention again when talking with a potential employer" (Respondent 67)	4	1
Brainstorming	The team brainstormed possible problems.	"Came up with the idea in a group brain-storm session" (Respondent 62)	1	1
Research	The team conducted research to identify a problem.	"Researching major problem areas in the world, which led us to investigate agriculture further" (Respondent 48)	1	2
Continuation	The team, or a team member, had worked on a project previously and worked on the same problem for the capstone project.	"Continuation of previous project run by a professor" (Respondent 15)	1	0

Table 1. Descriptions, examples, and frequencies of the six problem identification method themes identified in the survey data.

Three of the teams had respondents who did not know their need finding process because it was completed by another team member. Five of the teams reported that their problem topic (and presumably, definition) had been supplied by a client.

Figure 1 compares the distribution of chosen problem finding methods for the control group in comparison to the intervention group. While the small sample size precludes any statistical analysis on this data, we can qualitatively observe that the biggest difference between the two groups lies in the category of “research”. Specifically, a larger proportion of the intervention groups used this method compared to the control groups.

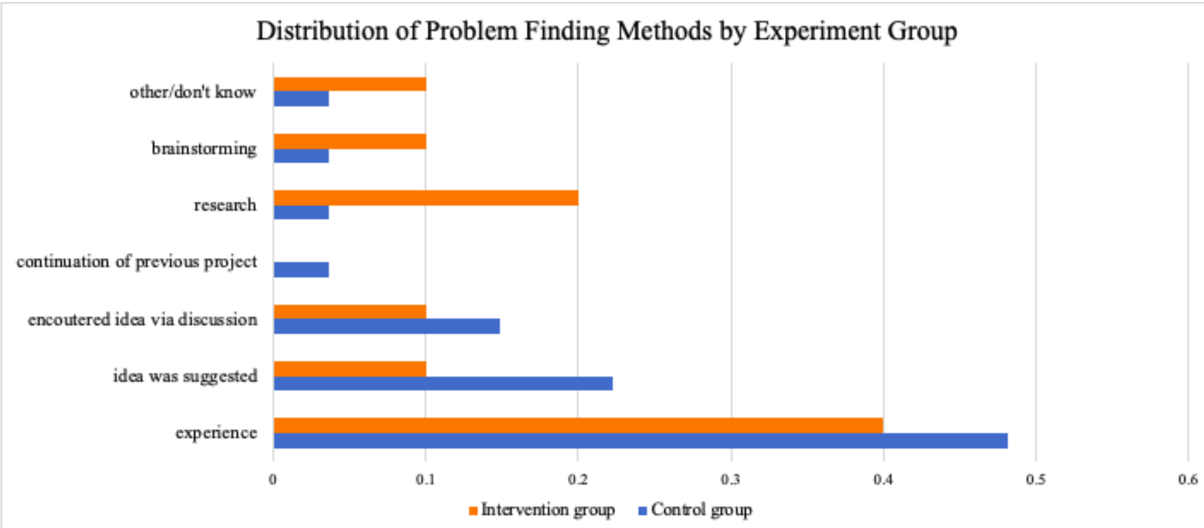

Figure 1. The proportions of intervention versus control groups distributed across the six known problem identification methods.

We were also interested in the methods teams used to gather more information on their topic, once the need was identified. The options listed, and their frequency of selection based on control or intervention group, were online research (control = 25, intervention = 10), observations (c = 18, i = 9), literature review (c = 17, i = 5), interviews or focus groups (c = 8, i = 6), user or client surveys (c = 5, i = 4), or a free form text option (c = 4, i = 2) with the most common additional method of informal discussions. Figure 2 shows the frequency distribution of each method for both groups. Once again, due to the small sample size we cannot draw any statistical conclusion, but we can observe a tendency for the intervention groups to engage in more user-centered approaches, specifically the “interviews/focus groups” and “user/client survey” categories. These are both methods which seek the expertise of the user, demonstrating the teams’ consideration of the end user in their solution design.

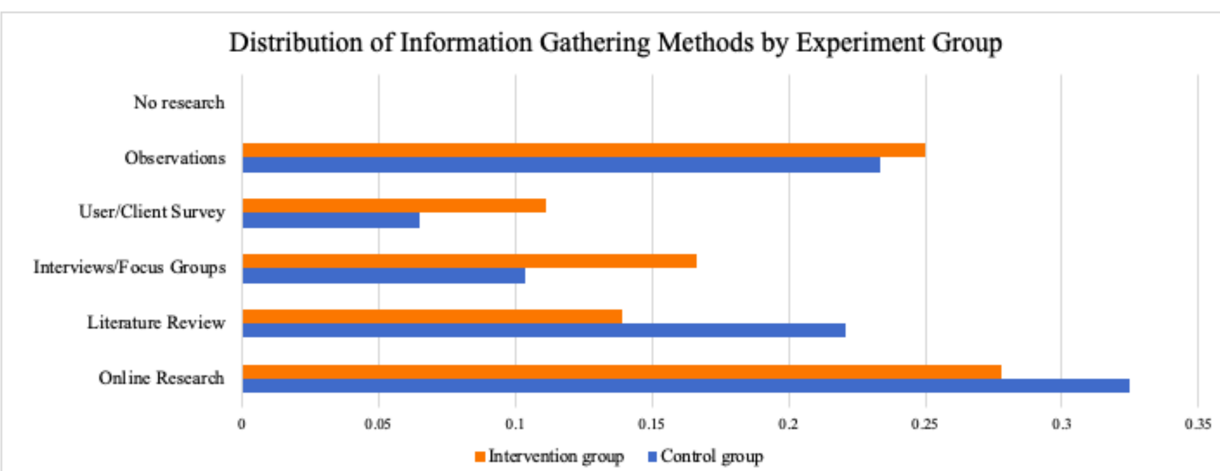

Figure 2. The distribution of the proportion of control and intervention groups across the six methods of gathering additional information on the project topic.

Of particular interest to our study was the question of whether there were any differences between the groups in terms of when they formed groups and selected a project topic. With regards to group formation, a notable finding is that the majority of teams who received the intervention formed their capstone group in their 3B term (65%), whereas most of those in the control group did not form their team until their 4A term (68%). This pattern is reversed in the case of project selection: a large majority of teams in the intervention group selected their problem in the 4A term (90%), whereas more than half of teams in the control group selected their problem in their 3B term (54%). These findings suggest that student teams that received targeted education on needs finding began to think about their project earlier than those who did not, but took longer to decide on their final topic.

Understanding how teams identified their problem, we also wish to study if the students thought the interventions affected these processes. To do this, we analyzed the average response to the Likert-scaled question on intervention effectiveness. The average response to the interventions in general was 2.6 out of 4 (where 4 was "very effective"). The most helpful intervention was the visit to the fourth-year capstone symposium with an average rating of 3.17, deeming the intervention as "helpful". The other two interventions received by the cohort captured in this study - a lecture and a workshop on problem finding - received rankings of 2.69 (a score between "helpful" and "unhelpful") and 2.01 ("unhelpful"), respectively. Accordingly, most of the student comments on the effectiveness of the interventions were directed to the symposium and how they benefitted from learning by example. The comments and numerical rankings conclude the symposium visit to be most effective, followed by a need finding lecture. Students reported that by visiting the symposium and intentionally assessing the design problems presented at the event, they were able to identify an appropriate "level of complexity" for capstone projects, and distinguish between "good" and "bad" problems. The underlying theme of all the comments was that, in general, the interventions encouraged them to begin looking at problems early. These comments align with the previous finding that teams in the intervention group began their projects earlier than those in the control group.

5. Discussion

This study investigated the problem finding processes students followed during their capstone projects and if designed interventions improved these processes. These objectives formed the basis of our two research questions. Below we summarize our findings and discuss the insight gained to answer those questions.

1. How do students identify, select, and justify their capstone design project problem statement, and are there structural differences in how students who received the intervention perform this step, versus other students?

From the survey data we learned that the most popular method for need finding, regardless if the students received any interventions, was through experience. Students were predominantly inspired by personal accounts and interactions, identified a problem, and sought to design a solution.

In the comparison of the control and intervention groups, we see that proportionally more students who received the intervention used research and brainstorming methods to aid in their need finding processes. This suggests that the interventions may have succeeded in encouraging students to use these as recommended methods for conducting proper need finding. The data also shows a tendency for students in the intervention group to form their capstone teams earlier but choose their topics later. We can infer a few things from this finding. First, the interventions in the 3B term may have encouraged students to begin thinking about their capstone project earlier. Second, the interventions may have also inspired a longer need finding process, thus delaying the selection of the final project topic. The more popular *research* and *brainstorming* methods among the teams in the intervention group tend to be more time consuming, but may result in better ideas. Since the interventions occurred before the start of the capstone project, it allowed for a longer and more exhaustive need finding process, especially for teams that formed early.

Finally, it was found that students who participated in the interventions were more likely to justify their topic using user-centered approaches. These students used interviews, focus groups, and surveys to gather more information on their topic and to inform their final design.

2. Were the interventions helpful in teaching students about needs identification?

After collecting data on the perceived helpfulness of the interventions, we can conclude that overall, the interventions were moderately helpful. Students identified the interventions as opportunities where they learned about proper need finding, practiced identifying good problems at the symposium, and encouraged them to begin thinking about their own projects. The most helpful intervention was the visit to the capstone symposium, as evidenced by the Likert ratings and qualitative feedback.

Due to the differences in engineering programs, the interventions were adapted to better align with the program goals. This makes it more difficult to compare interventions. Additionally, some programs received multiple interventions which, during the assessment portion of the study, introduce complexity in assessing the effectiveness of the individual interventions. Furthermore, not every program received a round of interventions. These programs were included in the control group to grasp a broader baseline, but we are unable to study the impact of interventions in these programs.

Currently, we are unable to draw strong conclusions from the data due to a small sample size, confounding factors, and the highly subjective nature of the data collection method. The survey results are based on student opinions of the interventions and the analysis is between-groups, thus there is increased unsystematic variation which we are unable to account for. Nevertheless, the results provide some insight into the perceived benefits of the interventions, which can be later supplemented with a more rigorous assessment of their effectiveness.

6. Future Work

Since the initial pilot of the in-class interventions in the Winter 2019 term, the instructors of the winter term third year design courses in two disciplines have inserted problem-finding lectures into their respective courses. They have also maintained the field trip component of visiting the fourth-year capstone design symposia for the third-year students. These permanent curricular changes show strong support for teaching problem-finding from instructors and creates an opportunity for future research on the impact of this instruction on fourth year projects.

Possible methods for analyzing the effectiveness of the interventions include evaluating the capstone problem statements across multiple years. Project outcomes from students who did not receive any need-finding education can be compared to those who did. The problem statements can be assessed in terms of their level of importance and appropriateness for a capstone project idea. Additionally, students' need finding processes can be assessed, including the degree to which they validated their work (in terms of secondary research, user feedback, surveys, etc.). As more students receive training inspired by the interventions, there will be a larger study population, allowing statistically significant conclusions to be drawn.

The study, and the interventions that will continue to be designed as a result of it, will bring two main benefits. First, they will support improvements to program quality by addressing an important curricular gap in engineering design education. Second, they will also capitalize on the commitment to the graduate attribute and continual improvement accreditation process [1] by providing a template for evidence-based program improvement, which can be used by programs in other areas of the curriculum.

7. Conclusion

The aim of this project is to improve the need finding capabilities of engineering students. A set of interventions was designed to teach students need finding skills prior to the commencement of their fourth-year capstone design projects. Due to the nature of co-op streaming at the University of Waterloo, only half of the students received the additional training. This allowed researchers to compare the effects of the interventions to a control group of students who did not receive them.

While there are limitations to this study and no strong conclusion can be drawn, there are two key findings. First, students who received the intervention formed capstone teams earlier, used more established need finding processes, like *research* and *brainstorming*, and decided on a final problem later than the students who did not receive the intervention. Second, the interventions – especially the visit to the capstone symposium of their older peers – were well received by students.

These findings suggest there is space for additional need finding training prior to students beginning their capstone projects. In doing so, students begin to think about the work earlier, granting them more time to complete an effective problem finding process and choose an appropriate problem.

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