ARE MULTIDISCIPLINARY DESIGN CAPSTONE'S STUDENTS MORE INNOVATIVE THAN MONODISCIPLINARY ONES?

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Abstract *–Educating Innovative minds is one of the main objectives of educational institutions. In curricula, capstone design courses provide the biggest opportunity for students to be innovative and creative. To prepare students for the multidisciplinary workplace, many institutions have initiated multidisciplinary capstones besides their departmental capstones. This paper explores innovation in multidisciplinary and mechanical engineering capstone design courses. Comparing multidisciplinary and monodisciplinary capstones with regard to the students' innovation will inform educational institutions about the best practices to prepare an environment for innovation to flourish. In this study, we define innovation as the ability to come up with creative ideas and being able to implement them. Our quantitative study measures innovation from rubrics that was assessed by supervisors and clients during the course of the projects. We also assessed innovation based on the students' self-report. So innovation was measured from both external (supervisors) and internal (students) perspectives. Our results show that functional diversity of multidisciplinary capstones affects students' ability to be innovative.*

Keywords: *Capstone Design Course, Multidisciplinary Education, Innovation, Creativity, Assessment*

1. INTRODUCTION

The fourth-year engineering capstone design courses are intended to prepare students for the real-world experiences as they graduate. To better prepare them to face the growing multidisciplinary work-space in the industry, educational institutions around the world have started to offer multidisciplinary capstone courses. Working in multidisciplinary capstone, exposes students to people from different disciplines as a practice for entering the work force. In one study, industry and academic representatives were asked about what is missing in engineering education. They both mentioned the ability to be creative and the ability to work in interdisciplinary environment as missing skill sets of recent graduates [1]. This gap can be filled by initiatives like multidisciplinary capstones. Multidisciplinary capstones expose students to multidisciplinary work environment. The multidisciplinary projects also create an opportunity for students to be innovative and creative based on the nature and scope of the projects. None of the students had the experience of working on an open-ended eight months project with an industry partner before getting to multidisciplinary capstone course.

There has been some quantitative research on the performance of multidisciplinary capstones that shows students who took multidisciplinary capstones had a better job placements [2]. However, there has not been an investigation around their innovativeness compared to monodisciplinary teams. Working with people from diverse backgrounds has been shown to foster innovation in literature. So in this study we investigate if students in the multidisciplinary capstone are more innovative than monodisciplinary capstone because of their knowledge diversity.

To be able to compare multidisciplinary and monodisciplinary we need to define innovation. In various studies on innovation, the term innovation is commonly defined as creativity (i.e., the generation and refinement of novel ideas and solutions), implementation (i.e., the creation of a physical product or design), and usefulness (i.e., how valuable and functional the product or design is) [3, 4, 5]. For the context of this study we defined innovation as the ability to come up with creative ideas and being able to implement them.

In the 2014-15 academic year, we conducted a preliminary study with students in multidisciplinary capstones. As part of this study, students were asked to rate themselves on how innovative they were. The study comprised of survey questions with more than 55% response rate and 11 one on one interviews with students. Our results showed that students rated themselves as very innovative in the multidisciplinary capstone. Moreover, students' innovativeness was positively correlated with the psychological safety of their team, the collaborative learning and the external feedback from supervisors and clients [6]. The majority of students perceived their design as innovative and novel. The results were based on a self-report that was only conducted on multidisciplinary students. Therefore, we extended the study to measure how innovative students are in both multidisciplinary and monodisciplinary capstone, from students', supervisors' and clients' point of view.

We hypothesize that because multidisciplinary capstone students come from diverse disciplines, their diverse background knowledge may be the source of new ideas or new combinations of ideas that can spur innovation in the long term. Literature suggests that functional diversity in teams is correlated with innovation [7,8]. Thus, we hypothesize that supervisors and clients will find more innovative behaviors in multidisciplinary students.

We investigate this by comparing multidisciplinary capstone teams by monodisciplinary ones. We investigate both element of creativity and implementation as we defined innovation as a combination of these two elements. Our quantitative analysis uses two measures of creativity and implementation from supervisors' point of view and clients' point of view for both multidisciplinary and monodisciplinary teams. We also analyze self-report data from students to investigate, if they think they were innovative in their design. We have collected data from the supervisors and the clients during the idea generation phase (first semester) and implementation (second semester). This data was collected during the 2015-2016 school year. This data consists of 19 teams from multidisciplinary capstone and 45 teams from the mechanical capstone.

At University of Toronto, the objective is to have a fair assessment and evaluation in the capstones. All students are evaluated with the same rubric, but their final grade is a holistic grade, which means this data is prone to supervisors' and clients' biases. This risk is unavoidable, since capstone design courses are extensive and they require many people from faculty and industry to be involved for assessments. Therefore, it is impossible to achieve 100% consistency.

The result of this quantitative analysis will shed some lights on the performance of multidisciplinary courses around innovation. This paper is part of a larger study that extensively explore all different factors that affect innovation in capstone design course.

2. MULTIDISCIPLINARY AND CAPSTONE COURSE INFRASTRUCTURE

Multidisciplinary capstone design course was introduced to Faculty of Applied Science and Engineering (FASE) at University of Toronto at 2013-2014 academic year by professor Behdinan [9]. Both multidisciplinary and mechanical capstones are full year courses. Students from across the faculty of applied science and engineering, can choose to substitute their departmental capstone with the multidisciplinary one. The decision to participate in the multidisciplinary capstone is optional. Anecdotal observations show that many students choose the multidisciplinary capstone because of the variety and scope of the projects. Nature of the projects is more challenging and interesting when defined for different disciplines to be involved. Also in many engineering disciplines, capstone is a one semester course. Choosing the multidisciplinary capstone allows student to do a full year capstone with a larger scope.

In both of these capstones, each team has a supervisor and an industrial partner. Supervisors are from academia to support and guide the students through the projects. Industry partners are the clients that bring the projects. Students are evaluated by both supervisors and clients. The deliverables for mechanical capstone course are: Project Requirement, Design Review, Final Design Specification and Showcase Poster. The deliverables for multidisciplinary capstone course are: Project Requirement, Design Proposal, Design Review and Critique, Final Report, Design Showcase and Design Portfolio. The grading distribution between these deliverables are fixed for the mechanical engineering capstone but can be negotiated by multidisciplinary capstone based on the nature of the projects [9]. The negotiation for grade distribution was in place because multidisciplinary capstones projects that were offered to the students were very diverse with projects within aerospace, health, finance, defence, manufacturing, and education [10]. For example, a very well defined project requires focus on prototyping stage. While another project might require an extensive research for development of project requirements. That's why students can negotiate which stage of the design process they want to focus on based on the nature of the problem they are given.

3. METHODOLOGY

The data for this quantitative analysis comprises of self-report assessments from students and external assessments form supervisors and clients.

An online questionnaire was sent to the students that composed of questions regarding factors that affect student's innovation. This online survey is a part of bigger research study that we are conducting. Students answered these questions using 5-point Likret Scale from "very strongly agree" to "very strongly disagree". A set of 11 questions was extracted from this questionnaire that represent student's perception about their innovativeness. We measure Cronbach's Alpha to measure the internal consistency of this set of questions. The cornbach's alpha for students' perception of their innovation is $\alpha=0.93$, which exceeded the reliability criterion of $\alpha \geq 0.7$. Since all these 11 questions are measuring the same construct with high internal consistently, we only analyze the question that asked students if they agreed or disagreed with this statement on a 5-point Likret scale: "Our team implements new ideas".

We also collected data from supervisors and clients from the assessment rubrics they filled out during the school year. To account for both creativity and implementation, we use rubrics from both the first semester and the second semester. This encompasses the idea generation phase in the first semester and the implementation and prototyping phase in the second semester. The rubrics design and deliverables itself is different between these two courses. After carefully examining these rubrics we found similar elements that represent assessment of creativity and implementation. We measure the creativity element and the implementation element, respectively, from the following indicators in the multidisciplinary capstone rubric: "Development of divergent (e.g. breadth and variety) design alternatives" and "The quality of the design product, including its performance relative to the requirements as defined in earlier deliverables and the quality and utility of any prototypes developed during the development of the final design". For mechanical capstone, we measure the creativity element and the implementation element from, respectively, the following indicators in the rubric: "Generate a diverse set of candidate engineering design solutions using appropriate idea-generation tools" and "Implement an appropriate design prototype to provide a proof of concept or enable test and evaluation". The rubrics had 4 categories. These categories are as follows: "Fail to Meet", "Below", "Meets", Exceeds". These data from supervisors and clients were normalized for both multidisciplinary and mechanical capstone for comparison. It is important to mention that the number of students registered in multidisciplinary capstones is smaller than the monodisciplinary capstone. The sample size was different.

4. RESULTS AND DISCUSSION

In this section we analyze the quantitative data from the supervisors, clients and students. Supervisors and clients evaluated students many times during the year. Two elements of rubrics were extracted from these assessments that are related to our definition of innovation. Students were also asked to evaluate themselves and their involvement was voluntarily.

4.1 Diversity in Alternative Designs

Figure 1 demonstrates the normalized histogram of the grades for the indicator that asks how diverse student's ideas were during the idea generation stage from an external point of view. The graph contains the data for both the multidisciplinary and the monodisciplinary.

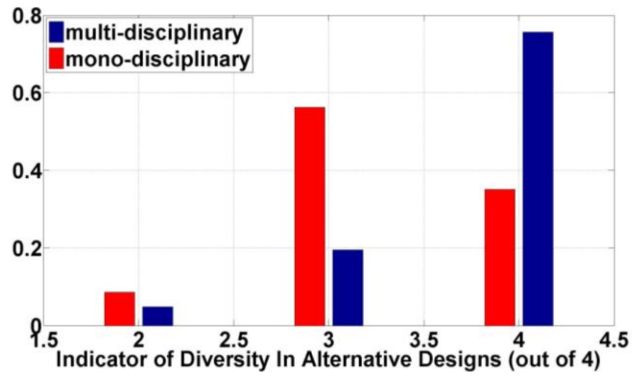

Figure 1

The average of grades for multidisciplinary capstone teams is 3.7073 while the average of grades for monodisciplinary capstone teams is 3.2656. Moreover, 75.61% of multi-disciplinary groups received a full mark (4 out of 4), while only 35.16% of monodisciplinary teams received a full mark. These statistics shows that multidisciplinary groups, from an external point of view, came up with more diverse solution during the idea generation stage of their project.

Because of their diverse disciplinary knowledge, multidisciplinary teams potentially came up with diverse alternative designs by linking ideas from different areas of investigation. There are many other contributing factors to student's creativity, like the project itself, supervisors, clients, student's individual capabilities and etc. But the trend suggest that multidisciplinary students were more creative during the idea generation phase.

The lowest grade for both groups was 2 which is given to only 4.88% of multi-disciplinary groups and only 8.58% of these groups. Therefore, a good number of groups for both multi-disciplinary and monodisciplinary have a diverse set of designs; however as indicated above the diversity of designs for multi-disciplinary groups were better than monodisciplinary groups.

This data is biased to the definition of the external assessors for what is defined as "Meets Expectation" or "Exceeds Expectation". Also the grade for each design team is given holistically which means this one element that we extracted from the rubric dose not necessary correlated with students' performance.

4.2 Quality of Design Prototype

To assess the quality of design prototypes, we analyze the grades from part of the rubric that indicates if student were able to implement their ideas and asks for the quality of their designs compare to the requirements they set earlier in the course. Figure 2 is a graph of the normalized histogram for the grades for both multidisciplinary and monodisciplinary courses. The data is based on the opinions of supervisors and clients.

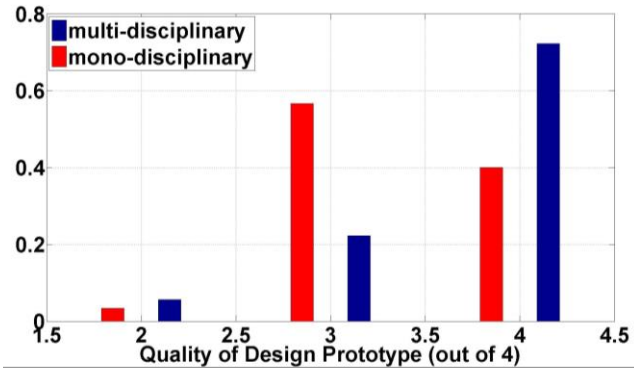

Figure 2

The multi-disciplinary teams received an average score of 3.667 and monodisciplinary teams received an average score of 3.3667. Furthermore, 72.22% of multi-disciplinary groups received a score of 4 out of 4 while only 40.00% of monodisciplinary groups got a full mark. The statistics indicate that multidisciplinary groups had a higher chance of coming up with a high quality prototype than monodisciplinary groups. This is potentially due to the diverse skill sets available on multidisciplinary teams.
The lowest grade for both groups was 2 which is given to only 5.56% (1 group) of multidisciplinary groups and only 3.33% (1 group) of monodisciplinary groups. Therefore, both multidisciplinary and monodisciplinary teams were able to come up with have high quality design prototypes. However, the quality of designs for multidisciplinary groups were better.

It is important to mention that “Meets” or “Exceed Expectation” can certainly have different interpretations for clients and supervisors. These evaluations and assessments have been done with various supervisors and clients with different educational backgrounds and mindsets. Although we normalized the data in our analysis, we should mention that the scores were recorded for 19 multidisciplinary teams and 45 monodisciplinary teams. Also the assessments are biased toward the attitude of assessors.

4.3 Student’s perception about their innovation

Students from both multidisciplinary and monodisciplinary were asked if they were able to implement their new ideas. Figure 3 shows the normalized histogram of students’ responses.

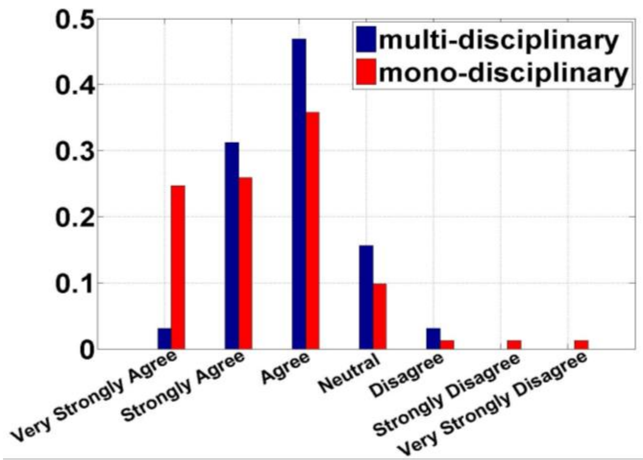

Figure 3 Students’ opinions about this statement: “Our team implements new ideas”

The multi-disciplinary students rating resulted in an average score of 2.8438 which is higher than 2.4568 from monodisciplinary students. Since “very strongly agree” was allocated to 1 in the Likert scale, this means that monodisciplinary student were more confident that they implemented new ideas. This was an unexpected finding. This could potentially because multidisciplinary students were more critical of themselves when they experienced engineering design from different lenses.

This phenomenon might be due to the fact that there are many aspects involved in a multidisciplinary project that not all people in the team necessarily understand and that might lead to a lot of second guessing and harsher self-criticism by multidisciplinary team members. Although the difference in the average scores by both groups is very small, this observation gives us some insights about the confidence level of multidisciplinary students.

Students’ perceptions of innovation could have been influenced by their definition of innovation and what was their expectation for implementation quality. There exists no other study in the literature that explores students’ confidence about their creativity and innovation in a multidisciplinary environment. This preliminary study proposed interesting research questions that should be further explored. How students’ perception of innovation and their confidence level can be changed in a multidisciplinary environment calls for further studies.

5. CONCLUSION

In this paper, we explored innovation in both multidisciplinary and monodisciplinary capstone design course. External reviewers’ assessment of innovation in two incidents during the school year was collected along with the self-report data from the students. Results shows that multidisciplinary students are slightly ranked higher by external examiners for their creativity and implementation of their new ideas. When students were asked about their innovation, monodisciplinary students ranked themselves higher. The reason behind this can be explored in future studies. It is interesting to further investigate factors like students' confidence or their definition of innovation, which could have resulted on lower students' perception of their innovation capabilities in multidisciplinary teams.

We suggest consideration of multidisciplinary project based courses for future design of educational curricula based on the insight gained from a preliminary quantitative analysis of the findings. Our results from external assessor confirms our initial hypothesis that multidisciplinary teams are more innovative that monodisciplinary ones because of their diversity. Our ultimate goal is to promote a culture of encouraging creativity in higher education that promotes innovation.

Acknowledgements

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