Team Level Factors Affecting Innovation in Multidisciplinary Capstone Design Course

by

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Abstract

Multidisciplinary capstones form student teams from different engineering disciplines to design, build, and test proof of concepts for an industry based project. To provide insight on multidisciplinary capstone’s performance and innovative outcomes, we explored innovation and factors related to innovation in both multidisciplinary and monodisciplinary capstones at the University of Toronto. Our investigation includes self-reported data and data from external assessments. We conducted both quantitative and qualitative research by collecting data from surveys, interviews, and video-recordings. External examiner’s and self-reported data show that multidisciplinary students are more innovative than mono-disciplinary ones. Our results show correlation between innovation and psychological safety, collaborative learning, internal and external communication, support for innovation from all parties, vision and feedback. Our research shows that aside from team’s diversity, support for innovation and culture of innovation is essential to realization of student’s creativity potential.
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# Table of Contents

## Contents

Acknowledgments.................................................................................................................. iii  
Table of Contents.................................................................................................................. v  
List of Tables .......................................................................................................................... viii  
List of Figures ......................................................................................................................... x  

1  Introduction.......................................................................................................................... 1  
   1.1 Motivation....................................................................................................................... 2  
   1.2 Framing the Research .................................................................................................... 4  
   1.2.1 Research Questions.................................................................................................... 5  
   1.2.2 Research Strategy....................................................................................................... 5  
   1.3 Road Map of the Thesis ................................................................................................. 7  

2  Literature review .................................................................................................................. 9  
   2.1 Capstone Design Course ............................................................................................... 9  
   2.2 Introduction to the Multidisciplinary Capstone Course Structure ............................... 10  
   2.3 Defining Innovation in the Context of Engineering Education .................................. 13  
   2.4 Factors Affecting Innovation ......................................................................................... 15  
   2.4.1 Vision ....................................................................................................................... 16  
   2.4.2 Feedback ................................................................................................................ 17  
   2.4.3 Psychological Safety ................................................................................................. 18  
   2.4.4 Functional Diversity ................................................................................................. 19  
   2.4.5 Collaborative Learning and Knowledge Transfer ................................................... 19  
   2.4.6 Support for Innovation ............................................................................................. 20  
   2.4.7 Communication ....................................................................................................... 21  
   2.4.8 Interdependence ....................................................................................................... 22
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Subsections</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>Hypothesis</td>
<td></td>
<td>22</td>
</tr>
<tr>
<td>3</td>
<td>Design of the Studies</td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>3.1</td>
<td>Survey Design</td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>3.1.1</td>
<td>Survey Validation</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>3.1.2</td>
<td>Reliability and Consistency</td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>3.1.3</td>
<td>Development of the Questionnaire</td>
<td></td>
<td>27</td>
</tr>
<tr>
<td>3.2</td>
<td>Design of Interview Questionnaire</td>
<td></td>
<td>38</td>
</tr>
<tr>
<td>3.3</td>
<td>Ethic Review</td>
<td></td>
<td>39</td>
</tr>
<tr>
<td>4</td>
<td>Preliminary Study</td>
<td></td>
<td>41</td>
</tr>
<tr>
<td>4.1</td>
<td>Methodology</td>
<td></td>
<td>43</td>
</tr>
<tr>
<td>4.2</td>
<td>Quantitative Data Collection</td>
<td></td>
<td>44</td>
</tr>
<tr>
<td>4.2.1</td>
<td>Statistical Analysis</td>
<td></td>
<td>45</td>
</tr>
<tr>
<td>4.2.2</td>
<td>Validation of Construct Measures</td>
<td></td>
<td>46</td>
</tr>
<tr>
<td>4.2.3</td>
<td>Bivariate Correlations</td>
<td></td>
<td>46</td>
</tr>
<tr>
<td>4.3</td>
<td>Qualitative Part</td>
<td></td>
<td>51</td>
</tr>
<tr>
<td>4.3.1</td>
<td>Qualitative Methodology</td>
<td></td>
<td>52</td>
</tr>
<tr>
<td>4.3.2</td>
<td>Qualitative Results</td>
<td></td>
<td>53</td>
</tr>
<tr>
<td>4.4</td>
<td>Conclusion</td>
<td></td>
<td>62</td>
</tr>
<tr>
<td>5</td>
<td>Exploratory Study</td>
<td></td>
<td>64</td>
</tr>
<tr>
<td>5.1</td>
<td>Methodology</td>
<td></td>
<td>65</td>
</tr>
<tr>
<td>5.2</td>
<td>Quantitative Part</td>
<td></td>
<td>66</td>
</tr>
<tr>
<td>5.2.1</td>
<td>Type of Data</td>
<td></td>
<td>66</td>
</tr>
<tr>
<td>5.2.2</td>
<td>Non-Parametric Tests</td>
<td></td>
<td>67</td>
</tr>
<tr>
<td>5.2.3</td>
<td>Validation of Construct Measures</td>
<td></td>
<td>69</td>
</tr>
<tr>
<td>5.2.4</td>
<td>Cleaning Data</td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>5.2.5</td>
<td>Test of Normality</td>
<td></td>
<td>71</td>
</tr>
</tbody>
</table>
List of Tables

Table 1 Bivariate Correlations (Spearman’s Rho), *p<0.05, **p<0.01 ............................................. 47

Table 2 Statistics on the analyzed responses of the qualitative study................................................. 66

Table 3 Mann-Whitney test statistics for multidisciplinary and monodisciplinary students....... 73

Table 4 Ranks of Mann-Whitney test on innovation and support for innovation. .................... 73

Table 5 Bivariate Correlations (Spearman’s Rho) for multidisciplinary students (*p<0.05, **p<0.01). ............................................................................................................................................. 76

Table 6 Summary of statistically significant correlations with innovation from Table 5. ....... 77

Table 7 Summary of statistically significant correlations between the variables in Table 5....... 82

Table 8 Bivariate Correlations (Spearman’s Rho) for monodisciplinary students (*p<0.05, **p<0.01). ............................................................................................................................................. 86

Table 9 Summary of statistically significant correlations with innovation from Table 8. ........ 87

Table 10 Summary of statistically significant correlations between variables in Table 8........ 89

Table 11 Cronbach’s Alpha values ........................................................................................................ 127

Table 12 Reliability test for psychological safety questions .............................................................. 128

Table 13 Reliability test for innovation questions .............................................................................. 128

Table 14 Reliability test for collaborative learning questions ........................................................... 128

Table 15 Reliability test for internal communication questions ...................................................... 129

Table 16 Reliability test for external communication questions .................................................... 129

Table 17 Reliability test for vision questions ..................................................................................... 129

Table 18 Reliability test for internal support for innovation questions .......................................... 129
Table 19 Reliability test for psychological safety questions .................................................. 130
Table 20 Reliability test for innovation questions .............................................................. 130
Table 21 Reliability test for collaborative learning questions ............................................. 130
Table 22 Reliability test for internal communication questions ........................................ 130
Table 23 Reliability test for external communication questions ....................................... 131
Table 24 Reliability test for vision questions ..................................................................... 131
Table 25 Reliability test for internal support for innovation questions ............................... 131
List of Figures

Figure 1 Overview of studies................................................................. 6

Figure 2 Data triangulation diagram....................................................... 57

Figure 3 Knowledge transfer dynamics in multidisciplinary capstone design teams............. 60

Figure 4 Diversity in alternative design scores for multidisciplinary and monodisciplinary capstone teams from external examiners.................................................. 94

Figure 5 Quality of design prototype scores for multidisciplinary and monodisciplinary capstone teams from external examiners.................................................. 96
Introduction

Final year capstone design courses in engineering help students practice their theoretical knowledge and expertise by applying what they have learned during their studies to a real world project with industry partners. The students work in teams to design, build, and test proof-of-concept systems (Goldberg, 2014).

This process prepares students to enter the workplace. The workplace has been changing rapidly. Now, engineering students are required to work and function in a multidisciplinary environment upon graduation. Because of that, many educational institutions have incorporated multidisciplinary capstone designs in their curricula.

There is limited qualitative and quantitative research on multidisciplinary teams and their effectiveness since educational institutions have only recently started to take more initiative in this area. The existing literature shows that multidisciplinary students are better off with job placement than monodisciplinary students (Hotaling, 2012); however, the existing literature has not investigated the innovativeness of multidisciplinary students. There are important questions to be asked and avenues to be explored about these multidisciplinary teams. For example, are multidisciplinary teams more innovative due to their functional diversity? What factors correlate with this innovation?

Finding the barriers that multidisciplinary teams are facing to be more innovative is also a great matter of importance in our educational system. Finding these barriers can help the development of a better multidisciplinary environment for our educational institutions that better simulates the real world scenarios. These barriers to innovation are not exclusive to multidisciplinary students and many are common to monodisciplinary students too. Therefore, the implication for practices
from this research in many aspects is applicable to both groups. The comparison between the monodisciplinary and multidisciplinary groups will only inform us about the effect of diversity of knowledge on innovation.

Literature revealed that in industry teams, support for innovation, vision, task orientation, and external communication displayed the strongest relationships with creativity and innovation. Although these studies are not in the context of engineering education and it is mostly focused on industry teams, we believe that the same relationship exists in our 4th year capstone design courses as these courses intent to simulate the real world environment for students.

Our research encompasses different factors that might help or hinder innovation in capstone design courses. The result of this research provides practical advice for educators. It will also reveal variables that affect innovation in general and variables that affect innovation only in specific situations.

1.1 Motivation

We live in a world that changes rapidly. In particular, the mandate of institutions and the culture of workforce have been subject to fast changes. To adapt to the pace of change, we need to constantly adapt our education systems to better prepare students for the real world. Today, innovation cycles are shorter and educational institutions should prepare students to function in such an environment.

Employers need cross-trained engineers who can take on multidisciplinary roles. To provide our students with such skill sets, our engineering education system should adapt and incorporate multidisciplinary work to match the need of industry. Accreditation bodies recently have started motivating educational institutions to incorporate multidisciplinary and interdisciplinary team in
their curricula. These skills have been identified as necessary skills for global competency in many studies (Codner, 2007).

From 2005 to 2012, approximately 35% of engineering capstone design courses in United States included interdepartmental or multidisciplinary teams. This is an increase from 21% in a 1994 survey of 1724 programs at 350 institutions (Hotaling, 2012, Howe, 2005).

In one study, industry and academic representatives were asked about what is missing in engineering education. Both academic and industry representative mentioned the ability to be creative and the ability to work in interdisciplinary environment as missing skill sets of recent graduates (Eggert, June 2003). This gap can be addressed by initiatives like multidisciplinary capstones.

There has been some quantitative research on the performance of multidisciplinary capstones that shows students who took multidisciplinary capstones had better job placements after graduation (Hotaling, 2012). However, there has not been an investigation about their innovativeness in comparison to monodisciplinary teams. Working with people from diverse backgrounds has been shown to foster innovation in literature. So in this study, we investigate if knowledge diversity of students in the multidisciplinary capstone allows them to be more innovative than students in monodisciplinary capstone. We also investigate whether a particular multidisciplinary initiative has been successful to fill the gap and better prepare students for the need of industry.

In our study, we explore different factors that lead to innovation in both monodisciplinary and multidisciplinary teams to come up with practical implications that allow one to remove the barriers to being innovative for students. Our goal is also to initiate the discussion around innovation and what leads to innovative behavior for engineering students in team work.
There has been research on facilitators and inhibitors of innovation in workplaces (Hülsheger, Anderson, & Salgado, 2009) and the references there in, but such an investigation has not been done in an educational setting for 4th year capstone design experiences. Exploring individual and team level factors that affect and predict innovation can help our educational institutions with their policy decisions to make the education environment more supportive of innovative behaviors. Creativity is often studied in education but not innovation. This might be because we rarely get to the implementation side of the innovation in our educational settings.

I took this multidisciplinary capstone course in 2013-2014 school year as a students. I acknowledge that his might have introduced biases during my data collection and analysis. I had a positive experience as the multidisciplinary capstone course created an environment for our team to be innovative.

1.2 Framing the Research

To measure innovation in our research, we need to define innovation in the context of engineering. 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?) (Paletz & Shunn 2009; West 2002; West & Farr 1990). For the context of this study, we defined innovation as the ability to come up with creative ideas and the ability to implement them. We want to investigate factors affecting innovation in capstone design courses and specially the multidisciplinary capstone. To investigate if diversity of multidisciplinary teams led to innovation we measured innovation in both multidisciplinary and monodisciplinary capstones from self-reported data and external assessments.
We framed this research as a team level factor because there are many other factors that affect innovation that we are unable to improve, modify or control in the context of engineering capstone design. For example, there are some students who are more creative than others by their pre-existing abilities. This is something that we can’t predict, change or improve. Their creativity might stem from the environment in which they have been raised or the schools they have attended and so on. Although the more creative students we have on the team, perhaps, the more creative ideas are generated in the team. But this is outside the scope of this research. Therefore, we plan to investigate factors related to innovation that can be changed to improve innovation in capstone design courses. We focus on how to flourish innovation and innovative behaviors as a team rather than focusing on individuals.

1.2.1 Research Questions

This research is intended to answer the following research questions:

- What factors have the largest effect on innovation in capstone projects?
- Are multidisciplinary students more innovative than the monodisciplinary ones due to their functional diversity?
- What are the factors that are related to or lead to innovation in 4th year engineering design course?
- Do external assessor/reviewers rate multidisciplinary students more innovative?

1.2.2 Research Strategy

There is an extensive range of well-established methodologies in the engineering education research literature. The main methodologies discussed in the literature are: Case Study, Grounded Theory, Ethnography, Action Research, Phenomenography, Discourse Analysis, and Narrative Analysis (Jennifer & Light, 2010). Research methodologies can also be categorized into more
general categories of qualitative methods and quantitative methods. A qualitative research is any analysis based on words (e.g., texts, interviews, or field notes from observations) (Kaplan, 2014), and a quantitative research is any analysis that uses numbers, either descriptively or in regression analysis (Kaplan, 2014).

I used both qualitative and quantitative methods to maximize my data collection and understanding of the problem. My main purpose of using the qualitative method was to provide examples and explanations for my quantitative results. My qualitative results from the first study also informed the design of my quantitative study for the second study. My qualitative results also served as a validation for some of my quantitative results. I utilized qualitative research to understand mechanisms that underlie relationships identified in quantitative research. I also quantify the qualitative data occasionally to represent qualitative evidence, potentially revealing patterns that might not be visible otherwise. The mix methods played confirmatory and complementary role in my research and this has been the practice in literature (Small, 2011).

My research consists of two studies. Figure 1 shows the detail for each study:

<table>
<thead>
<tr>
<th>Study 1 (Preliminary Study)</th>
<th>Study 2 (Exploratory Study)</th>
</tr>
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<tbody>
<tr>
<td>• 2014-15 school year</td>
<td>• 2015-16 school year</td>
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<tr>
<td>• Multidisciplinary students only</td>
<td>• Both multidisciplinary and monodisciplinary Students</td>
</tr>
<tr>
<td>• Online survey</td>
<td>• Online survey</td>
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<tr>
<td>• 11 one on one interviews</td>
<td>• Video recording of one team followed by one on one interviews</td>
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Figure 1 Overview of studies
The quantitative portion of my research is the two online survey that I conducted twice over the last two years. My qualitative research includes two sets of interviews over the past two years and a series of video recording from one multidisciplinary team and one monodisciplinary team. Since the quantitative method and the qualitative method were conducted in 2014-15 and 2015-16 school year, the first study informed the second study.

1.3 Road Map of the Thesis

This thesis contains two major studies, many aspects of which have been published in conference proceedings. There are six conference papers in total that have been published in American Society for Engineering Education (ASEE) and Canadian Engineering Education Association (CEEA) conference Proceedings (Balouchestani, Greenacre, Behdinan, 2016 & Balouchestani, Behdinan, 2016 & Balouchestani, Zhu, Behdinan, 2016 & Balouchestani, Zouda, Behdinan, 2016 & Behdinan, Balouchestani, 2016 & Milicevic, Balouchestani, Tihanyi, & Behdinan, 2015).

Chapter 2 contains an extensive literature review of factors affecting innovation. We also describe the background and the existing research about multidisciplinary education and innovation in this chapter. At the end of this chapter we state our hypothesis based on the existing research and literature around innovation.

Chapter 3 is the detail design for both studies which consists of a survey design and an interview questionnaire design. We use surveys as a means to collect quantitative data in both studies. Furthermore, we use interviews to collect qualitative data in both studies. In this chapter, we discuss the design and selection of these questions.
Chapter 4 is on the preliminary study that was conducted during the 2014-15 school year. This study consists of an online survey and a set of one on one interviews. The study has been conducted only with multidisciplinary students.

Chapter 5 contains the results of the second study that was a modified and extended version of the first study. To compare multidisciplinary and monodisciplinary teams, the second study consists of survey questions for both multidisciplinary and monodisciplinary teams. Qualitative data was also captured through one on one interviews and video recordings.

Chapter 6 summarizes the implication for practice from this research that can be used to enhance students’ experience and to create an environment that supports innovative behaviors.

Chapter 7 presents the conclusions and future work, and summarizes the contributions of this research. The chapter also discusses limitations of the current work, and suggests improvement strategies.
2 Literature review

This section will present the literature review of research around capstone design courses, multidisciplinary capstone and factors affecting innovation in teams.

2.1 Capstone Design Course

Across the world, undergraduate engineering programs culminate in capstone design courses. A capstone design course is defined as: “an integrative course in which student teams synthesizes solutions to open-ended, real-world problems” (Dym, Agogino, Eris, Frey, & Leifer, 2005).

Students go through many iterations of the design process by defining the problem and then specifying functions, objectives, and constraints. Then, they propose many alternative creative solutions. After analyzing the solutions, they use a formal decision making method to choose their final design. Then they start implementing their solution and go through design iterations.

The general practice is to separate senior design courses by discipline. Evolving from monodisciplinary to multidisciplinary capstones will allow students to collaboratively work on a design problem by exchanging their expertise, knowledge, and experience.

University of Toronto used to only have monodisciplinary capstone design which is consist of about four students from the same engineering discipline (e.g., mechanical, electrical, biomedical, industrial, or aerospace). After the initiating of multidisciplinary capstone, students from different disciplines formed team to work together. Since these engineering students need to survive and thrive in multidisciplinary professional environments after graduation, the university environment should prepare them by teaching them as many lessons as possible about challenges and opportunities. Therefore systematic quantitative and qualitative studies of practical and successful
structures should be undertaken as more engineering schools initiatives multidisciplinary capstone design courses.

2.2 Introduction to the Multidisciplinary Capstone Course Structure

The multidisciplinary capstone design course (APS490) at University of Toronto was developed in 2013-2014 under the Natural Sciences and Engineering Research Council of Canada (NSERC) design chair program in the Faculty of Applied Science and Engineering with the leadership of Professor Behdinan (Behdinan, Pop-Iliev, & Foster, 2014). The goal was to create opportunities for students to challenge themselves by working in teams with members from different disciplines. The goal was for students to expand their engineering knowledge and skills beyond their single discipline (Hotaling 2012, Kamran Behdinan 2014).

The range of projects that is offered to the students is very diverse including projects in aerospace, health, finance, defence, manufacturing, and education. Students with expertise in chemical engineering, electrical engineering, computer science, mechanical engineering, industrial engineering, materials science, and/or engineering science are involved with the course (Milicevic, Balouchestani, Tihanyi, & Behdinan, 2015). There are 6 departments and 3 institutes within the Faculty of Applied Science and Engineering that are involved in this course (Electrical and Computer Engineering, Mechanical and Industrial Engineering, Chemical Engineering and Applied Chemistry, Material Science and Engineering, Civil Engineering, Engineering Science, Institute of Biomaterial and Biochemical Engineering, Institute of Robotics and Mechatronics and Institute of Multidisciplinary Design and Innovation).

Each project has a client from an industry partner that is supporting the project and a supervisor from the academy. Clients provide the requirements and the criteria for the projects. Supervisors
support the students in their design process and provide them with the insights and information. Both the clients and the supervisors give feedback to the students from different perspectives.

The goal of the multidisciplinary capstone course is to combine different disciplinary design modules into a final proposed engineering design. For students to do so, not only do they need to apply their disciplinary knowledge but they also need to integrate their module in to other teammate’s modules which requires understanding of each other’s modules or subsystems. The goal is also to provide an environment for 4th year students to be more innovative with their final capstone project.

Since when this multidisciplinary course was established, nearly 240 students have benefited from this course by being exposed to diverse range of projects from engine design to health care delivery to financial algorithm. Fifty-six projects have been completed for 30 clients. When students who took the undergraduate capstone course were asked whether they would suggest this course to an upcoming student, 94% responded affirmatively.

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. My 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. The monodisciplinary capstone courses have different structures across the Faculty. There are one semester or two semester capstones. There are some with the involvement of industry partners and some that is restricted to the university environment. For the purpose of this research, we focus on
the monodisciplinary capstone course at the department of Mechanical and Industrial Engineering (MIE). The capstone course in MIE is two semesters with involvement of industry partners. The multidisciplinary capstone is an enhanced version of the MIE capstone that brings students together from across disciplines. For the sake of comparison, in this research, we compare the multidisciplinary students with monodisciplinary in MIE which consist of mechanical and industrial students each working on their monodisciplinary capstone.

The deliverables for the MIE capstone course are: Project Requirement, Design Review, Final Design Specification and Showcase Poster. The deliverables for the multidisciplinary capstone course are: Project Requirement, Design Proposal, Design Review and Critique, Final Report, Design Showcase and Design Portfolio. The grade distribution between these deliverables are fixed for the mechanical engineering capstone, but can be negotiated by multidisciplinary capstone teams based on the nature of the project (Behdinan, et al., 2014). 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. While for some projects a very well defined project requires focus on the prototyping stage, there are other projects that require extensive research for development of project requirements. Therefore, students can negotiate on which stage of the design process they want to focus based on the nature of the problem they are given.

Another major difference between the MIE capstone and multidisciplinary capstone course is the portfolio requirement. As defined by the course guide: “The Design Portfolio deliverable captures evidence of student engineering design knowledge, abilities and experiences. It must include evidence from APS490 and may include evidence from other curricular, co-curricular, or extra-curricular design experiences. The Portfolio supports student claims of proficiency as an engineer
and engineering designer, and is intended for a wide audience that will include their Supervisor and may include e.g. prospective employers, collaborators, and research supervisors.”

2.3 Defining Innovation in the Context of Engineering Education

Engineering is one important field to embrace possibilities and face challenges and problems in our world of constant, rapid change. Innovation and creativity in engineering is about addressing change efficiently through the development of novel technologies (Cropley, 2015). The huge impact of change on our natural and social life leaves us with little choice but to be innovative and creative in solving problems and shaping our future. However, the notions of creativity and innovation are not agreed-upon concepts: the two terms are usually distinctly defined, although some scholars use them interchangeably (Badran, 2007). Conceptualization of innovation also varies between different disciplines: factors, such as the discipline’s dominant paradigm, and aim, means and social context of innovation (among others), tend to shape and guide different disciplinary definitions of innovation (Baregheh, et al, 2009). As this study aims to explore different factors the affect innovation in a multidisciplinary engineering team, it is important to set a clear definition of innovation that aligns with the context and objectives of engineering capstone projects.

To tangibly define innovation, we built on Paletz & Schunn’s (Paletz S. B. F., et al, 2010) definition of creativity and innovation: Creativity is “a person, process, product, or environment that formulates, results in, displays, or encourages both usefulness (appropriateness, correctness, or value) and originality/novelty” (p. 74). Innovation on the other hand involves “the elements of relative rather than absolute novelty, intentional benefit to individual, group, organization, or wider society, and the application/implementation of the creative ideas” (p. 74). The rationale for aligning with these definitions is threefold: first, the notion of creativity is inclusively broad (i.e.
a person, process, product, or environment), yet it selectively emphasizes novelty as a main criterion for creativity. Second, both definitions of creativity and innovation underscore usefulness as their main goal. Third, the definition of innovation encompasses implementation as an integral part. This perfectly fits with a main characteristic of engineering: making ideas come into reality. Hence, we define innovation as the ability to develop creative ideas and to implement them.

However, in order to ‘enact’ innovation there should be a supportive environment: a ‘culture of innovation’ (Herbig & Dunphy, 1998). The main characteristics of an innovation-supportive environment are encouraging risk-taking and tolerating failure (Tushman & Nadler, 1986). These two interrelated elements are essential to encourage the expression of novel ideas and putting these ideas to work. Tied to these element, is the space allowed for ideas to originate at the grass root level, rather than being dictated from above, as well as the acknowledgment and rewarding of ideas (Hülßheger, Anderson, & Salgado, 2009). At the team-level (which tends to be a dominant and favorable condition in most work and educational settings), there is a list of factors that are argued to enhance innovation and make it possible. These factors were compiled by Hülßheger, Anderson, & Salgado (2009) through a meta-analysis of 30 years of published primary research on innovation and the workplace. These factors include goal interdependence (i.e., the extent to which individual team members’ goals are interdependent); team’s vision (i.e., sharing a common valued outcome); task orientation (i.e., agreement on quality of work); cohesion (i.e., the commitment of team members to their teams); and internal and external communication (p. 1129 - 1132). The study also lists other important factors that tend to support team-based innovation but seem to be highly contextualized. Among these factors are job-relevant diversity, which refers to the variety in team members’ education, profession, knowledge, skills and expertise (p. 1129). Other factors include team size and participative safety. In different contexts, some (or may be all) of these factors intersect to shape innovation differently.
As engineering capstone projects usually aim to engage senior students in the design of new products to face continuously emerging needs and challenges, innovation tends to be a main demand. Furthermore, most of the problems that we face today are interdisciplinary, requiring interdisciplinary and multidisciplinary knowledge, skills and expertise in order to face them efficiently. Hence, our study aims at examining how different factors affect innovation in a multidisciplinary, engineering capstone projects. The results of this study would provide strategies to better support innovation in engineering education.

2.4 Factors Affecting Innovation

The diversity of background knowledge has been identified as a key factor for team innovation (Thompson, 2003). But there are many other factors like productive communication and the management of possible problems with team processes that also affect innovation. Many variables are related to the development of innovation in teams whether it is multidisciplinary or not.

As mentioned, diversity of knowledge is only one of the factors that affect innovation and we explore this factor by comparing monodisciplinary and multidisciplinary capstones. But we also want to explore other factors that affect innovation in engineering capstones beyond diversity of knowledge. Therefore, we extensively searched the literature to find team level factors that affect innovation. There exists extensive research around team innovation in industry but little in educational settings. We decided to work on a variety of factors so that we can provide a framework for further analysis.

Psychological safety, collaborative learning, external and internal communication, constructive feedback and support for innovation have been shown to correlate positively with innovation in industry teams. Team size and team longevity has been shown to negatively affect innovation. There are many other factors that have been investigated in the literature that are not applicable to
the case of team work in capstones. It is important to mention creativity has been extensively researched in education and there are many different tests and data to measure creativity. But we want to investigate innovation that encompasses implementation in engineering and we want to investigate it with respect to team work. Therefore, the literature around student’s creativity is outside for the scope of this research.

When we conducted the first study, we considered these factors:

Feedback from all parties, applying, teaching and learning disciplinary knowledge, psychological safety.

After analyzing the results of the first survey along with the interviews and discussing the existing literature, we refined these factors and included the following factors in the second study:

Psychological safety, collaborative learning, internal and external communication, vision, Support for innovation (From team members, client, supervisor).

2.4.1 Vision

Literature suggests that having a shared vision across the team members is important to team innovation (West, 1990 & West, Anderson, 1996 & Gilson, Shalley, 2004). “Vision is an idea of a valued outcome which represents a higher order goal and motivating force at work” (West, 1990, p. 310). To adjust this definition to the educational problem at hand, we should think of valued outcome as a potential prototype or design and the goal as the expected grade for the course as it is often the motivation for many students. Vision also assesses common understanding of objectives and commitment to team goals. Vision has also been referred to as “clarity of and commitment to objectives” (West & Anderson, 1996, p. 682). In the case of educational setting, this translates to student’s commitment to get through the design process and prototyping stage.
This commitment, based on my experience, in most cases is closely related to students’ grade expectation of the course. Having the same vision across the team can motivate individual team members to enhance their innovative performance. This vision needs to be shared by all team members. If vision is shared and all the team members have the same understanding of objectives, there will be less conflict and disagreement and the environment will be ready for innovation. Although the connection between vision and innovation is found in industry teams, we believe that having the same vision is still an important factor in educational setting.

2.4.2 Feedback

Discussing errors, seeking feedback, and seeking information from teammates is associated with improved team performance and innovation (West, 2002 & Edmondson, 1999). Thus, we wished to ask students if they felt they received enough feedback from their supervisors, clients, or each other. We expect that students who get more feedback from their teammates to report more team innovation, since feedback from teammate’s helps students consider other options and choose better solutions (West, 2002).

The extent by which feedback from clients and supervisors affects psychological safety, knowledge transfer, and teammate feedback is difficult to predict, and may depend on the specific supervisor, client, student, and the design problem. However, anecdotal evidence suggests that feedback from clients may correlate negatively with innovation, as often clients will tell capstone teams of a specific solution that they would like to see.

For teammates to give each other feedback, they must be comfortable in doing so. They must believe that it is safe for them to take interpersonal risks with each other. There must be a sufficient degree of psychological safety in the group for teammates to share their discipline-specific
knowledge and provide feedback on each other’s designs (Edmondson A., 1999). Therefore, psychological safety is another factor affecting innovation.

2.4.3 Psychological Safety
Psychological safety is “the shared belief among members of a team that it is safe to take interpersonal risks” (Edmondson, 1999). Psychological states and behaviours of the team can affect innovation (Paletz & Schunn, 2010). According to the literature, the presence of high psychological safety in a team concludes innovation behaviour (Post, et al, 2009). Moreover, low psychological safety prohibits innovative behaviour (Yuan, et al, 2010). In an industry environment, psychological safety in a team enables contradictory perspectives and unique skills to be valued. This in turn enables the team to draw on individual knowledge and expertise to be more innovative (Schulz-Hardt S., et al, 2006).

Although psychological safety is important for innovative behaviour, it is more important for multidisciplinary teams because of their diversity. Multidisciplinary teams are more likely to experience conflict because members do not share the same mental model of the design problem and subsequently do not understand what the appropriate solutions and/or the technical details of the solutions are (Cronin, et al, 2007 & Bunderson J. S., et al, 2002). For example, if students from one discipline demand a disproportionate share of the project budget for their modules and the other students cannot evaluate whether that allocation of funds is technically justified, then the conflict can only be resolved if the students are able to fill the knowledge gap. Without sufficient psychological safety, the team is unable to communicate and resolve the conflict. The funds may not be allocated as necessary, and the project will ultimately suffer. Because psychological safety is necessary for collaborative learning and team efficacy (Edmondson A., 1999), we aim to explore the degree of psychological safety present in multidisciplinary capstone teams.
2.4.4 Functional Diversity

Functional diversity refers to the variation in education and professional experience between members of a team (Cabrales, et al, 2008 & Paletz, et al., 2010), as opposed to demographic, cultural, or ethnic diversity. Though students in multidisciplinary capstone are all within engineering, they have greater functional diversity than students taking a monodisciplinary capstone. As mentioned above, functional diversity may lead to greater conflict (Cronin, 2007). However, it has been found that the functional diversity of multidisciplinary teams leads to greater innovation (Paletz S. B. F., 2010 & Drach-Zahavy A., 2001 & Dunbar, 1997). Literature indicates that the breadth of knowledge available to the team due to functional diversity can potentially lead to innovation (Hulsheger, Anderson, & Salgado, 2009). This is believed to be the case because a more diverse group has more information and resources to draw from. We wish to explore the effect of functional diversity by comparing the monodisciplinary and multidisciplinary students.

2.4.5 Collaborative Learning and Knowledge Transfer

Collaborative learning is defined as “careful, purposeful and attentive interactions around learning” (Ryle, 1949 & Post C., et al, 2009). Another source defines collaborative learning as a team’s ability to effectively manage its learning interactions (Post, 2012). In the context of capstone design courses, collaborative learning is a team’s ability to transfer knowledge between team members with different background and skill sets. Collaborative learning happens both in multidisciplinary and monodisciplinary capstone as students either have different skill sets and expertise or acquire them due to their role in the team and they must communicate them with each other to integrate their knowledge and come up with one final design. We believe that there should be more collaborative learning in multidisciplinary teams as it involves teaching, learning and applying disciplinary knowledge. Also each student’s knowledge and expertise in multidisciplinary teams is more distinct compared to monodisciplinary teams.
Moreover, more communications occur in multidisciplinary teams because team members must explain their own disciplines to each other (Drach-Zahavy, 2001). That is why, one of the objectives of this study is to examine knowledge transfer by measuring the amount by which the students are applying and teaching their own discipline and the amount by which they are learning their teammates’ disciplines. The process of simplifying complex, technical ideas to teach them to others, and the questions offered by teammates learning the material may lead to novel insights.

2.4.6 Support for Innovation

Support for innovation is defined as “expectation, approval and practical support of attempts to introduce new and improved ways of doing things in the work environment” (West, 1990, p. 315). Adapting this definition to the context of education and capstone design courses, we can define support for innovation as: expectation, approval and practical support of attempts to introduce new ideas or improved ways of doing things in a capstone project. This include tolerating risk taking and failure and acknowledging student’s efforts.

Support for innovation have been found to positivity affect innovation (Hülsheger, Anderson, & Salgado, 2009, Amabile et al., 1996; Madjar, Oldham, & Pratt, 2002; Scott & Bruce, 1994; Shin & Zhou, 2003). Therefore, we intend to examine whether clients and supervisors are actively encouraging students to find more innovative solutions. To frame this in the context of education and capstone courses, we categorized support for innovation into three categories: 1) Internal support for innovation from members of the team 2) External support for innovation from supervisors and 3) External support for innovation from clients.

We believe that all of these three factors affect innovation. Since supervisors and clients have the authority and control over the assessment, their attitude and support toward innovation play an important role. Thus, we designed a series of survey questions to measure the support for
innovation both from the team members and from external sources which in this case are supervisors and clients.

2.4.7 Communication
Communication has been found to be one of the main source of innovation since it enables sharing information and ideas which is a viable source of innovation (Keller, 2001). Often times, communication is categorized as internal and external (Keller, 2001). Therefore, we wish to investigate the effect of communication on innovation from both an internal and external perspective.

2.4.7.1 Internal Communication
Literature suggests that increased internal communication and increased frequency of meetings of professionals working on research and development projects is associated with innovation (Hülsheger, et al, 2009 & Keller, 2001). Therefore, we expect to see a similar relationship in the context of education. The more students communicate with each other and with the supervisor and client, the higher the chance that they will come up with innovative ideas because innovation does not happen in isolation.

2.4.7.2 External Communication
External communication is defined as any communication with experts outside of the team. This is beyond communication with supervisors and clients. People with diverse background are more likely to have higher external communication as they know more experts in different disciplines. Therefore, they have a broader network from which to ask questions and seek advice. Researchers have found that external communication is a strong predictor of innovation in workplace (Hülsheger, Anderson, & Salgado, 2009). Research shows that external communication with experts outside the team improve the chance of coming up with new perspectives and ideas (Perry-
We wish to explore the effect and existence of external communication in both multidisciplinary and monodisciplinary capstones.

2.4.8 Interdependence

Our primary goal is to investigate the relationship between the above-mentioned factors and innovation in the context of education. But these factors correlate with each other too. Therefore, their effect on innovation is not distinct. They have a direct effect and an indirect effect through their relationship with other factors. For example, psychological safety covaries with collaborative learning. So there is a direct effect from psychological safety on innovation and there is indirect effect through its effect on collaborative learning. The same is true for all the variables that are dependent on each other. We investigated different factors in our first and second studies. In each of these studies, we expect some of these factors to correlate with each other on top of their correlation with innovation.

As we discussed earlier, many of the existing literature are on teams situated in industry rather than in an educational setting. Therefore, their findings should be explored and potentially validated in education setting. The timeframe that the teams spent together, their incentive and the environment is very different from that of industry. We wish to investigate these factors and their correlation in educational environment with multidisciplinary capstone.

2.5 Hypothesis

These factors are shown to relate to innovation in industry teams. We will investigate if the same relations exist for capstone design teams. Based on our literature review, we developed the following hypothesis for both studies:
1. The following factors will positively predict creativity and innovation scores:
   a. Functional diversity (i.e. being in a multidisciplinary team)
   b. Psychological safety
   c. Collaborative learning: the measure of collaborative learning is different between the two studies. Apply, learn, and teach is used for the first study only
      1. Apply
      2. Learn
      3. Teach
   d. Internal communication
   e. External communication
   f. Vision
   g. Support for innovation from team members
   h. Support for innovation from clients
   i. Supports for innovation from supervisors
   j. Feedback from team members, clients and supervisors

2. Multidisciplinary capstone teams will be more innovative than monodisciplinary capstone teams.
3  Design of the Studies

As we mentioned earlier, this thesis encompasses two studies. For both of these studies we utilized surveys as a means of collecting quantitative data and interviews/video recordings as a mean of collecting qualitative data. The following sections describe, in detail, how we designed these elements.

3.1  Survey Design

We used surveys as a mean to produce a statistical description of the student population with regard to our ideas and with regard to our investigation around innovation and other factors affecting it in multidisciplinary and monodisciplinary capstone. We used a survey methodology book by Groves et al. (2009) as a reference guide for our survey design. Here is a brief description of construct, latent and observed variable as I will be using them throughout my thesis:

Construct: The idea or information the survey is seeking to examine (e.g. psychological safety).

Latent/Unobserved Variable: An abstract concept that cannot be measured directly, but is measured indirectly.

Measurement/Observed Variable: a variable that we are taking a direct measurement of. (e.g., a specific question in the survey is an observed variable, and the response the student gives is the measurement of the variable.)

We investigated different constructs and latent variables that cannot be measured directly by using observed variables. To measure a latent variable or construct, we capture indicators that represent the underlying construct. For example, innovation, psychological safety, and other constructs studied in this investigation were measured by asking students a set of questions about components that build each of these construct. In particular, psychological safety is measured by asking...
students questions about its component like trust, comfort, ability to voice opinions and etc. For this survey to give an accurate description of a construct, two conditions were considered:

1. We tested the survey with small sample of students before sending it out to the target student population to avoid potential miscommunication or misunderstandings of questions.

2. We validated the survey responses with reliability test (i.e., Cronbach’s alpha). In addition, we explored the existing literature in different field of studies and based our questions on previous research and survey validation.

For a survey to be effective, the sample must be an accurate reflection of the target population. We did our best to increase the response rate, but as we also mention in the results section, this study is still biased by the self-selection process and limited sample size.

3.1.1 Survey Validation

We accounted for the extent to which the survey accurately measures the intended construct. The difference between the measured response and the true response determines the validity of the survey. The more closely correlated the measured responses are with the true responses, the more valid the survey is. Since we do not have the true responses, we have to estimate the validity. One way in which we checked the validity of the survey was by investigating if the questions that are very similar, or testing the same construct produce similar measurements. We also used Cronbach's alpha test to check the survey’s validity and reliability.

We also incorporated reverse questions in the survey to identify if students are actually responding to their survey or they are superficially filling the survey without paying attention to the questions. If any student did not answer the reverse question properly based on his/her previous responses, we deleted the student’s response from the survey data to increase validity and reliability.
Response biases are a systematic difference between the true values of responses and the observed responses. Because the measures are subjective, and are not objectively verifiable, bias technically does not apply to them.

3.1.2 Reliability and Consistency

Reliability is the measurement of variability of answers over repeated conceptual trials. Reliability addresses the question of whether respondents are consistent (or stable) in their answers. We checked for low variability in answer from one response to the next.

Since we used many indicators for one construct (e.g., we have 9 questions that are all testing psychological safety), we selected Cronbach’s alpha to test reliability. Cronbach's alpha is a measure of internal consistency, i.e., how closely related a set of items are as a group. It is considered to be a measure of scale reliability. Following the decision to use many indicators to measure a construct, we have made the following assumptions:

1. All questions are indicators of the same construct
2. All questions have the same expected response deviations (i.e., reliability is the same for all questions)
3. The measurements of the items are independent. (i.e., the answer from one item does not influence the answer to another question)

Cronbach's alpha test reveals a reliability coefficient. Nunnally has indicated 0.7 to be an acceptable reliability coefficient (Nunnally, 1978). If overall alpha value is bigger than 0.7, then we are confident that these questions are measuring the same construct. When reporting Cronbach's alpha in the result section, we disclose two coefficients. The first Cronbach's alpha coefficient employs the covariance among the items, whereas the second alpha is based on
standardized items and hence employs the correlations among items. The second Cronbach’s alpha coefficient is based on the assumption that all of the items have equal variances.

3.1.3 Development of the Questionnaire

In the following sections, we describe each part of our questionnaire. We explain the origin of these questions and briefly discuss the related literature. In this questionnaire we measure psychological safety, innovation, collaborative learning, internal and external communication and vision, internal support for innovation as a latent constructs. But we measure feedback from all parties, apply, learn, teach, support for innovation from supervisors and clients as observed variables. This is the full version of the questionnaire that we developed. However, we used part of these questions in the first study and used a selected set of these questions in the second study.

Based on the literate, a good Likert scale should be 5-7 items long and have a clear and monotonically increasing or decreasing set of responses (Matell & Jacoby, 1971). All of our Likert scale falls under these conditions.

3.1.3.1 Psychological Safety

Many studies have reported that psychological safety is related to innovative behavior and overall team performance. It has been found in the literature that this construct is even more important in the study of multidisciplinary teams. Because multidisciplinary teams do not share the same mental model and their members each have a different communication strategy on top of the normal difference that with others in the team at the time of team origination. Therefore, we dedicated part of the survey to measure the degree of psychological safety in both multidisciplinary students and monodisciplinary students. This part of the survey consisted of nine questions that is modified for this research study. We used the survey that was developed by researchers at the Institute for Multidisciplinary Design & Innovation (IMDI) by combining items from Edmonson 1999 with
items from Edmonson and Mogelof 2006 (Scharf, Behdinan, & Foster, 2014). Since these questions are being modified, we ran a reliability test for each time that we used these question to examine measurement’s reliability and to make sure each of these questions are measuring the same construct, which in this case is psychological safety. This latent variable consists of observed variables such as: “ability to bring up tough issue”, “safe to take risk”, “skills and “talents are valued and utilized” and so on. Here is a list of questions measuring this construct:

Please indicate how much you agree or disagree with the following statements by selecting one for the following responses: Very Strongly Agree, Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree, and Very Strongly Disagree.

1. If you make a mistake on this team, it is often held against you.

2. Members of this team are able to bring up problems and tough issues.

3. People on this team sometimes reject others for being different or being from another discipline.

4. It is safe to take a risk on this team.

5. It is difficult to ask other members of this team for help.

6. No one on this team would deliberately act in a way that undermines my efforts.

7. Working with members of this team, my unique skills and talents are valued and utilized.

8. There is free and open communication within my team.

9. Within my team, we challenge each other’s ideas in a constructive way.
3.1.3.2 Innovation

As we discuss earlier, innovation is a combination of creativity and implementation and practicality. Creativity is meant to be measured once when the design proposal is handed in, because that immediately follows the period of ideation. Implementation, practicality, and creativity are measured after handing in the final deliverable.

In this section, we explain the questions that we developed to measure creativity, implementation and innovation in different stages. The questions were developed for both students and external examiners (clients and supervisors). However, the questionnaire for clients and examiners was not sent out as the teaching team did not agree. Therefore, I used the rubrics as the source of data for measuring innovation from client’s and supervisor’s point of view. We will disclose the set of questions that was designed for client and supervisor in the bank of questions as these questions were developed as part of our research and can be a source of later studies.

The first 11 questions were developed and validated by Scharf et al. from seven different sources (Carmeli, Reiter-Palmon, & Ziv, 2010; Jabri, 1991; Janssen, 2000; Liang, Hsu, Chang, & Lin, 2013; Miron, Erez, & Naveh, 2004; Scott & Bruce, 1994; Zhou & George, 2001). Scharf et al. demonstrated a high internal consistency between all of the responses, showing that the questions are either very similar, or are collectively a valid test of innovation. We slightly modified the wording to make it applicable to the context of capstone and subsequently ran the reliability test to make sure these questions are still valid. These questions are more focused on the creativity part of the innovation rather than implementation. Further survey design should create a balance between these two elements of innovation. The reason that these questions were not modified to create this balance was the time limitation to be able to validate a new set of questions.
3.1.3.2.1 Students

Please indicate how much you agree or disagree with the following statements by selecting one for the following responses: Very Strongly Agree, Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree, and Very Strongly Disagree.

1. Our team demonstrates originality in our working methods and/or results.
2. Our team generates new work-related ideas that can be used.
3. Our team identifies opportunities to use or develop new products or processes.
4. Our team looks for new and fresh ways to deal with problems.
5. Our team suggests new ways of performing tasks.
6. Our team implements new ideas.
7. Our team suggests new ways to achieve goals.
8. Our team seeks out new technologies, processes, techniques and/or ideas for solutions.
9. Our team links ideas that come from different areas of investigation.
10. Our team thinks in a flexible way and can take ideas from one context and use them in other contexts.
11. Our team is good at getting others excited about new ideas, solutions and/or processes.

We added the item below. This one is considered separately, and not included with the above questions in an aggregate creativity score. Because it is a measure of how many ideas or designs a team could come up with, it is a very direct measure of divergent creativity.

Please provide the most precise answer possible. Please estimate a number range if the true answer is unknown.

12. How many completely different ideas for designs did your team come up with?
3.1.3.2.2  Client and Supervisors

The following questions were developed for the clients and supervisors to gain an objective measure of innovation. Questions 2-4 are taken from the student’s questionnaire. Questions 1, 5 and 6 are new. They are meant to use the supervisors’ and clients’ experience to provide an objective measure of the novelty, diversity, and “radicalness” of the student’s creativity. Here is the list of questions:

Please indicate how much you agree or disagree with the following statements by selecting one for the following responses: Strongly Agree, Agree, Somewhat Agree, Neutral, Somewhat Disagree, Disagree, or Strongly Disagree.

1. All of the designs proposed by this team are distinct and unique solutions to the problem they are tasked with.
2. This team links ideas that come from different areas of investigation.
3. This team’s proposed designs are novel and original solutions.
4. The team demonstrates originality in their working methods and thought processes.
5. The proposed designs are unexpected.
6. Each of the proposed designs is an entirely different approach to the problem.

The following is a modified version of the Bonen Scale (Dayrl, Bonen, & Myersdorf 1993), that was used by Miron-Spektor et al. 2011 as a direct measure of creativity. We changed the definition given at each of the 4 levels.

8. Please divide 100 points among the following 4 different levels of innovation, allocating the greater numbers of points to the levels that better described the team’s activity.

1. Not Creative: duplicating existing technology, ideas, or techniques
2. Somewhat Creative: making minor modifications to existing technology, ideas, or techniques to meet the design requirements

3. Creative: pioneering new technologies, ideas, or techniques that are not new, but have not been used in this way before; using ideas or techniques that they could not have learned in class

4. Very Creative: developing breakthrough, brand new technologies, ideas, or techniques by combining ideas in new ways or developing entirely new techniques

3.1.3.3 Collaborative Learning

Literature suggests that collaborative learning has a direct effect on innovation in many industry teams. In the context of education, we believe collaborative learning is important for capstone teams because students are required to share their knowledge and collectively get to a final design. We think this is even more important in multidisciplinary capstone teams as they rely on each other’s expertise and they do not have the same background of knowledge. We designed a questionnaire based on existing information to measure this construct and find it’s correlation to other constructs and variables. We are also interested to see the difference between the multidisciplinary and monodisciplinary students in cooperative learning score.

The collaborative learning questions are based on Post’s measure of “cooperative learning” (2012). Our list includes items from the sources that Post used. Questions are originally from Janz & Prasarnphanich 2003 and they have been modified for the context of capstone. Here is the list of questions:

Please indicate how much you agree or disagree with the following statements by selecting one for the following responses: Strongly Agree, Agree, Somewhat Agree, Neutral, Somewhat Disagree, Disagree, or Strongly Disagree.
1. When we work together on our team, we try to make sure everyone on the team learns from each other.

2. When we work together on the team, our performance evaluations depend in part on how much all members learn.

3. When we work together on the team, I have to make sure the other members of the team learn if I want to do well on the project.

4. When we work together on our team, the work is divided up so that everyone has a part and everyone has to share.

5. When we work together on the team, everyone’s ideas are needed if we are going to be successful.

6. When we work together on the team, I have to find out what everyone else knows if I am going to be able to complete my part of the project.

7. On this team I like to share my ideas and work material with other members of the team.

8. Members of my team learn a lot of important things from each other.

9. We take the time as a team to examine areas in which we need more skill or experience.

10. My teammates and I exchange information in a timely manner.

11. On this team, people provide constructive feedback.

12. On this team, people actively listen to teammates.

13. On this team, people make sure that teammates understand important information and instructions.

14. My teammates and I have recently discussed what we did right or wrong on the project.

In the first study in 2014-15 school year, instead of measuring collaborative learning, we measured the degree of knowledge transfer which basically lead to the idea and measurement of collaborative learning in 2015-16 study. Here is the list of questions from first study:
To what extent (6-point scale: strongly disagree--strongly agree) did you:

1. Apply knowledge from your own discipline?
2. Learn knowledge from other disciplines?
3. Teach knowledge from your own discipline?

3.1.3.4 Team Climate Inventory

The Team Climate Inventory (TCI) was developed by Anderson and West in 1998, and measures four factors that have been shown to predict innovation. We only included vision and support for innovation from these factors in our study. The TCI and the shortened version used here was validated by Kivimaki and Elovainio in 1999. We included TCI because these measures have been previously validated by many scholars over the years. Here is the list of questions:

Please indicate how true the following statements are of your team by selecting one of the following responses: Strongly Agree, Agree, Somewhat Agree, Neutral, Somewhat Disagree, Disagree, or Strongly Disagree.

Vision

1. Our team is in agreement with on our team objectives.

2. Our team’s objectives are clearly understood by all members of the team.

3. Our team’s objectives can actually be achieved.

4. Our team’s objectives are worthwhile to our client.

Support for innovation

1. People in this team are always searching for fresh, new ways of looking at problems
2. In this team we take the time needed to develop new ideas

3. People in the team cooperate in order to help develop and apply new ideas

3.1.3.5 External Support for Innovation

The teaching team indicated that clients will often let students know that they have a particular design in mind, and direct students towards it, and/or discourage them from exploring many options. These kind of behavior is also possible to come from supervisors. That’s why, we decided to explore the support for innovation from external parties. In literature, Sagaldo et al. (2009) and Anderson and West (1998) found that support for innovation is a very important factor in innovation in industry teams. Therefore, we developed a new questionnaire to take a deeper look into the effect of support for innovation in capstones teams. We categorized support for innovation into internal support and external support. Internal support for innovation is the support that is coming from team members and the external support for innovation is the support coming from the supervisor and the client in the case of capstone design course. The internal support has been already included under the team climate inventory. Here are the questions for the external support for innovation:

Please indicate how much you agree or disagree with the following statements by selecting one for the following responses: Strongly Agree, Agree, Somewhat Agree, Neutral, Somewhat Disagree, Disagree, or Strongly Disagree.

1. Your client encourages the team to produce a novel and innovative design.

2. Your supervisor encourages the team to produce a novel and innovative design.

3. Your supervisor pushed you to try many different approaches towards the design problem.

4. Your client pushed you to try many different approaches towards the design problem.
5. Your teammates encourage you to produce a novel and innovative design.

6. Your team made finding a new and better designs a priority.

7. Your team did not want to spend much time thinking of design ideas.

In the first study we also asked students if they received enough feedback from clients, supervisor and teammates. Here is the list of questions:

1. The amount of feedback I received from the client was: (select one)
2. The amount of feedback I received from the supervisor was: (select one)
3. The amount of feedback I received from my teammates was: (select one)
   a. Too little  b. Enough  c. Too much

3.1.3.6 Internal Communication

This section of the survey investigates the degree of internal communication between team members. We believe effective internal communication between team members might have a great effect on innovation and having innovative outcomes. These are all questions taken and adjusted from Pinto & Pinto 1990 and Keller 2001:

Please indicate how much you agree or disagree with the following statements by selecting one for the following responses: Strongly Agree, Agree, Somewhat Agree, Neutral, Somewhat Disagree, Disagree, or Strongly Disagree.

1. I communicate with my teammates to resolve problems turning our design ideas into a final deliverable.

2. I communicate with my teammates to brainstorm new ideas for our design.

3. I communicate with my teammates to get project-related information.

4. I communicate with my teammates to get approval to carry out a design idea

5. I communicate with my teammates to receive feedback on my performance
6. Team members of my team help each other be more effective in their work. (E.g., show each other ways of working faster or getting more work done).

7. Team members fail to give each other important information. (R)

8. Team members share information and resources to complete their work.

9. Team members communicate with each other to complete capstone work

3.1.3.7 External Communication

This section assesses the degree of external communication between the teams and any subject matter expert outside of their team. In literature, sharing and communicating ideas with people outside of the team is reported to be linked to innovation in industry. We wish to investigate this link in educational setting. These are all items taken from Ancona & Caldwell (1992) and modified to be more specific to capstone, without changing the underlying question.

Please indicate how much you agree or disagree with the following statements by selecting one for the following responses: Strongly Agree, Agree, Somewhat Agree, Neutral, Somewhat Disagree, Disagree, or Strongly Disagree.

1. I or my teammates ask someone outside of the team and not the client or supervisor for help resolving a design problem.

2. I or my teammates review the design with people outside of the team.

3. I or my teammates obtain materials or resources from people outside of the team.

4. I or my teammates collect technical information from individuals outside of the team.

5. I or my teammates find new technical ideas and processes, but NOT by asking teammates.
3.2 Design of Interview Questionnaire

In this study I interviewed students in two consecutive years. In 2014-15 school year, I interviewed 11 students from multidisciplinary capstone. The list of questions for this interview can be found in appendix A. My main goal was to understand their multidisciplinary capstone experience. I asked them to describe their team work and their experience (as positive or negative). I intended to see if they benefited from the disciplinary knowledge of their teammate. I also asked questions regarding knowledge transfer. This was a semi-structured interview as I wanted to ask students further questions based on their responses. I investigated factors like motivation, communication, extracurricular activities and many others in these interviews. The result of these interviews informed my survey questions and interview questions for the 2015-16 study.

In 2015-16 school year, I also conducted interviews with ten students. Six students from the multidisciplinary capstone and four students from the monodisciplinary (mechanical) capstone. In this study, instead of having one person per team interviewing with me like last year, I interviewed students from one multidisciplinary team of six people and one monodisciplinary team of four people. The reason for the strategic change was to get the full picture on dynamics of the teams. I felt during the first round of interviews that I am getting partial information. For example, while the person I was interviewing might have had a great positive experience, it may not necessary mean that everyone in the team had a similar experience. Therefore, to get a better understanding of the situation, I studied two teams, one from multidisciplinary and one from monodisciplinary. On top of the interviews I had with them toward the end of the school year, I video recorded serval of their meetings to get a closer look at their team dynamic and interaction.

The list of the questions that I used for the second round of semi-structural interviews for 2015-16 school year can be found in Appendix B. There were specific questions for each student based on
my observation from the video recordings that is not included here for confidentiality. The second round of interviews included questions regarding psychological safety, vision, communication, risk taking, support for innovation and other factors that might have influenced innovation. Many of these questions are inspired from the survey questions. I wanted to have evidence, example, and better understanding of my quantitative results by these interviews and video recordings.

3.3 Ethic Review
Two ethics proposal were submitted and approved by the Board of Ethics at the University of Toronto for both studies. One proposal was submitted for 2014-15 school year and another for 2015-16 school year. Based on the new requirement of provostial approval for the second study, a provostial ethic proposal was also submitted and approved for collecting data from both students and supervisors. These three approval letters can be found in Appendix D. All elements of this study have been reviewed by the ethics board (online survey, interviews and video recordings). The letter of consent for students participating in each stage of this research can be found in Appendix E.

For confidentiality in data collection and reporting, all questionnaire responses were assigned a random numeric identifier and all interview participants were assigned pseudonyms. It was optional for students to participate in our online survey, interviews and video recordings. We advertised a chance to win $100 gift card and $300 gift card for survey participation in the first and second online survey, correspondingly. Students were compensated $20 for doing the one on one interviews and $30 for doing the interviews and video recordings.

We explored different options for students’ recruitment and involvement. Student participation in return for 1% complication mark was rejected by the teaching team. Coding the questionnaire to give students feedback based on their answers was also found ineffective as students would
graduate by the time that we could give them any results and feedbacks. Giving feedback to students to improve their innovation/team dynamics/communication can be potentially effective for first and second year students.
4 Preliminary Study


This preliminary study was conducted during the 2014-2015 school year. The purpose of this study was to explore different factors that might be related to innovation and then revise and enhance the study for next year and iterate.

In this preliminary study, we explored the relationship between innovation (at the individual level and team level), psychological safety, knowledge transfer (application of one’s knowledge), and feedback from teammates, supervisors, and clients in a multidisciplinary engineering capstone course. We also investigated barriers that multidisciplinary capstone teams encountered to be innovative by observing the teams’ psychological safety behaviors from interviews. We also explored how knowledge transfer is happening in these teams and how it correlates with other factors. The study examines these factors and outcomes in a multidisciplinary course only. The second study includes the monodisciplinary students to create a baseline of comparison.

In this preliminary study, when asking students about their experiences with innovation, psychological safety, knowledge transfer, knowledge use, and feedback, we expected to find that some of these factors are correlated. For instance, team innovation is the overall level of innovative
activity of the team. When students meet and discuss the design problems that they are tasked with, each extra person is able to consider and provide additional solutions. This provides a larger bank of solutions to draw from, more inputs, and more critiques for evaluating candidate solutions. Hence, it is unsurprising that increased internal communication and increased frequency of meetings of students or professionals working on R&D projects is associated with more innovation (Keller, 2001). We expected to find that students who taught their teammates, students who learned from their teammates and students who received more feedback from their teammates would also report higher levels of team innovation.

Here, we consider individual innovation to be the number of design ideas one team member comes up with and refines. It is likely that the individual creative process is aided by two elements we measured: 1) applying one’s own discipline specific knowledge and 2) teaching it to others. If a student is applying his or her own discipline-specific knowledge, he or she is likely to be able to produce a greater number of useful solutions to his or her design problems than if he or she cannot make use of his or her area of expertise and instead is learning it for the first time.

By teaching their discipline-specific knowledge to others, engineers may improve their own ability to come up with new ideas, because teaching involves relating basic principles to the design solution and often involves using analogies. By explaining technical knowledge to other students at a conceptual level, students must spend more time considering the relationship between the problem requirements and the principles behind their solution. By returning to a broader, more theoretical picture of the problem, students are presented with more possible solutions than if they only consider solutions they were introduced to in their training. By using a top-down approach to problem solving, students are more likely to see the underlying problem and deduce a new solution.
that is logically the best solution, rather than opt for a known solution because the design problem is similar to a problem taught in the class (Ball, et al., 1997).

By using analogies to teach, engineers practice using this method of solution-finding that is commonly used for scientific discovery. In science, analogies are used to find new hypotheses by comparing the current unknown problem with a solved case that has some similarities, prompting one to ask if both can be understood in the same way. In engineering, using an analogy may act the same way. By saying problem A is basically the same as problem B, it follows that the existing solution to problem B may also work for problem A (Dunbar, 1997). Thus, by thinking of analogies to teach teammates about one’s discipline, one practices using this method of finding a solution.

However, as mentioned above, for students to engage in this knowledge transfer, and to discuss and debate different solutions, the capstone team members must feel sufficient psychological safety. To be innovative, capstone students should be able to ask each other for input, to discuss and to debate design decisions, and to propose innovative, risky ideas without fear of rejection. They must be able to resolve conflicts and communicate effectively. This has been found in numerous studies (Edmondson, 1999 & Post, et al., 2009 & Scharf, Behdinan, & Foster, 2014). Thus, we expect that students with higher psychological safety scores to also report that they taught their teammates more often, learned from their teammates more often, and received more feedback from their teammates, and to have higher team innovation scores.

4.1 Methodology

A mix of quantitative and qualitative methods was used in this study. In this study, our focus was multidisciplinary students only. The data was self-reported. We did an online survey with a 55% response rate. Moreover, we conducted 11 one-on-one interviews with students over a course of one year. Our questionnaire included a set of questions on innovation, psychological safety,
knowledge use and transfer, and feedback. We examined our data to find relationships between these variables that can help us understand the dynamics of innovation in a multidisciplinary capstone course. We found correlations between the psychological safety score of teams and their collaborative learning and team efficiency. We also found that team innovation has a particularly strong correlation with psychological safety and is also significantly correlated with teammate’s feedback score. To enhance trustworthiness of the collected data, the questionnaire and the interview were designed with multiple questions that targeted the same, as discussed in the survey design section.

Students who completed the survey were entered in a draw to win $100. The survey was completed by 46 out of the 83 students in the course, for a response rate of 55% and sample size of N = 46.

Data scrubbing and analyses were completed using SPSS by:

- removed missing data,
- checked reliability of measures by calculating Cronbach’s alpha
- performed bivariate correlational analysis of all factors with each other

Eleven students also participated in one on one interviews. A blub was sent out through emails to all multidisciplinary students about the interviews and its $20 compensation. Only eleven students contacted me and I interviewed them all. So there was no pre-selection or criteria. Students self-selected to participate in interviews as it was the case for survey.

## 4.2 Quantitative Data Collection

We asked capstone students a set of survey questions that collectively measures innovation. Students were asked to evaluate their own level of innovation, as well as that of their team as a whole.
4.2.1 Statistical Analysis

Although each set of questions used to measure the psychological safety, the individual innovation, and the team innovation have been previously validated by Scharf et al. (Scharf, Behdinan, & Foster, 2014), we calculated Cronbach’s Alpha to measure the internal consistency of each set of questions measuring each construct.

A data that is collected on a Likert scale is considered ordinal scale data. Therefore, for such data, using parametric tests and taking means are controversial, and considered less robust (Jamieson, 2004). The median is considered a conservative measure of central tendency for ordinal scale data than the mean. Thus, the median of each student’s responses to questions assessing each construct was taken as the student’s score for that construct. For example, the median of all of the responses a student gave for questions about psychological safety was taken as the student’s psychological safety score.

We used Spearman’s Rho to test for bivariate correlations between scores for psychological safety, team innovation, individual innovation, as well as the responses students gave regarding feedback, applying knowledge, learning knowledge, and teaching knowledge from their discipline. We used this test to see if there was a correlation between the scores for psychological safety, team and individual innovation, and responses to questions about collaborative learning and feedback.

A correlation between innovation and psychological safety or between any of these construct, can also be broken down into the correlation between their observed variables. For example, the nine observed variables that measure psychological safety also correlate with other observed variables. I decided to only state the correlation between latent variables and not between each pair of observed variables.
4.2.2 Validation of Construct Measures

Cronbach’s alpha was used to measure the internal consistency and reliability of each question measuring each construct. Measures of psychological safety ($\alpha = 0.777$), team innovation ($\alpha = 0.945$), and individual innovation ($\alpha = 0.922$), all exceeded the reliability criterion of $\alpha \geq 0.7$. Thus, we are confident that each construct is being measured by its set of survey questions.

But the alpha value for collaborative learning was 0.549 which is low according to the alpha table value (Appendix C). Therefore, the three questions on collaborative learning were considered separately, since they cannot be considered a reliable test of a single construct. Using either too few features or using the wrong set of features in the survey can be the cause of low value of Cronbach’s alpha for collaborative learning.

4.2.3 Bivariate Correlations

Correlations between all measures are found in Table 1. In summary, team innovation has a particularly strong correlation with psychological safety ($p<0.01$), and is also significantly correlated with individual innovation ($p<0.01$) and teammate feedback ($p<0.05$). Individual innovation also correlates with learn ratings ($p<0.05$) and teach ratings ($p<0.01$). Psychological safety also correlates with apply rating ($p<0.05$) and teach rating ($p<0.05$), as well as teammate feedback ($p<0.05$). Apply ratings are strongly correlated with teach ratings ($p<0.01$). We found that ratings of supervisor feedback are negatively correlated with ratings of teammate feedback ($p<0.05$). Finally, students’ ratings of supervisor feedback and client feedback have a relationship that approaches significance ($p=0.07$).
<table>
<thead>
<tr>
<th></th>
<th>Psychological Safety</th>
<th>Team Innovation</th>
<th>Individual Innovation</th>
<th>Apply</th>
<th>Learn</th>
<th>Teach</th>
<th>Client Feedback</th>
<th>Supervisor Feedback</th>
<th>Teammate Feedback</th>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Team Innovation</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Individual Innovation</td>
<td>0.072</td>
<td>0.402**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apply</td>
<td>0.388**</td>
<td>0.199</td>
<td>0.267</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learn</td>
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<td>0.105</td>
<td>0.291*</td>
<td>0.139</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teach</td>
<td>0.330*</td>
<td>0.275</td>
<td>0.438**</td>
<td>0.706**</td>
<td>0.079</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Client Feedback</td>
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<td>-0.029</td>
<td>0.092</td>
<td>-0.132</td>
<td>0.038</td>
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<td>0.029</td>
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<td>-0.001</td>
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<tr>
<td>Teammate Feedback</td>
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<td>0.325*</td>
<td>0.044</td>
<td>0.177</td>
<td>0.233</td>
<td>0.173</td>
<td>-0.028</td>
<td>-0.339*</td>
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</table>

Table 1 Bivariate Correlations (Spearman’s Rho), *p<0.05, **p<0.01
There was a moderate, positive monotonic correlation between psychological safety and teammate feedback, which was statistically significant ($r_s(46) = .322, p < 0.05$). Furthermore, there was a strong, positive monotonic correlation between team psychological safety and innovation, which was highly statistically significant ($r_s(46) = .695, p < 0.001$). The correlations between psychological safety and team feedback and between psychological safety and team innovation are consistent with the literature (Edmondson, 1999 & West M. A., 2002 & Post C., et al, 2009). Future studies using path analysis should be completed to determine whether psychological safety predicts innovation and feedback, and whether more feedback predicts greater innovation. The strong correlation between psychological safety and innovation is a key finding in this study. This can assist us to better design multidisciplinary capstone courses.

There was a moderate, positive monotonic correlation between team innovation and individual innovation, which was highly statistically significant ($r_s(46) = .402, p <0.001$). The finding that team innovation correlates with individual innovation was not expected. It seems unlikely that students that come from teams with high overall innovation would also be much more likely to be innovative themselves. Students are not placed into their groups according to their ability to be innovative. It is possible that students rated their team’s innovation similarly to their own individual innovation. However, since team innovation and individual innovation each have a different set of correlations with the factors studied, this is unlikely to be the case. This finding ought to be further examined and it can potentially change the project and the student matching process in such a course.

There was a moderate, positive monotonic correlation between apply and psychological safety, which was highly statistically significant ($r_s(46) = .388, p <0.001$). Students were asked whether
or not they applied their discipline specific knowledge. But, the question did not specify whether they applied their knowledge in meetings or just within the capstone course, in general. So, it is surprising that applying discipline specific knowledge significantly correlates with psychological safety. One may expect that the degree to which students apply their discipline specific knowledge would be determined by the dimensions of the design problem. However, if there exist a poor psychological safety, a student may feel unable to advocate for a particular design solution that makes full use of his or her discipline specific knowledge. Distinguishing between the role that team dynamics and the design problem itself play in deciding how much a student is able to apply his or her engineering education is worth further exploration. Because giving students the opportunity to practice applying their education is a key objective of the multidisciplinary capstone design course.

There was a very strong, positive monotonic correlation between teach and apply, which was highly statistically significant ($r_s(46) = .706, p < 0.001$). The fact that applying knowledge from one’s own discipline and teaching it to one’s teammates are closely correlated is also unsurprising and is encouraging. It suggests that students are sharing their own discipline-specific knowledge, which they must use for their portion of the project, with the rest of their team. If the theories, discussed here, regarding knowledge transfer and innovation are correct, applying knowledge from one’s discipline and teaching it to teammates should encourage innovation in the multidisciplinary capstone course.

There was a weak, positive monotonic correlation between learn and individual innovation, which was statistically significant ($r_s(46) = .291, p < 0.05$). Individual innovation correlates with learning a new discipline from one’s teammates. It is possible that this encourages students to engage in integrative thinking, as students place new knowledge into their existing mental frameworks
(Paletz & Schunn, 2010). This process may lead to more creative thinking as students make connections between disciplines, and may notice solutions in their teammate’s discipline that may apply to their own (Post C., 2009).

There was a moderate, positive monotonic correlation between teach and individual innovation, which was highly statistically significant ($r_s(46) = .438, p < 0.001$). Individual innovation correlates with students teaching their teammates their own discipline. This may support the theory that the mental activities involved in teaching help students discover more possible design solutions than if they did not have to engage in teaching, either through broad picture thinking or coming up with analogies.

There was a moderate, positive monotonic correlation between teammate feedback and team innovation, which was statistically significant ($r_s(46) = .321, p < 0.05$). This finding is consistent with literature that state discussing errors, seeking feedback, and seeking information from teammates is associated with improved team performance and innovation (West M. a., 2002 & Edmondson, 1999). Therefore, it is important to encourage internal communication between team members that encompass giving feedback. Also have a psychologically safe environment for the team is essential for students to initiate feedbacks.

There was a moderate, negative monotonic correlation between teammate feedback and supervisor feedback, which was statistically significant ($r_s(46) = -.339, p < 0.05$). Unexpectedly, we found a negative correlation between the amount of feedback that students received from their teams and the amount of feedback they received from the supervisors. It is possible that students who do not receive enough feedback from their teammates turn to their supervisors. It is also possible that students in groups with poor psychological safety and/or with little communication or knowledge transfer seek information from their supervisors instead. In either case, supervisors may provide
students means of avoiding knowledge transfer with their teammates. This should be further investigated to ensure that supervisors are able to promote teamwork and knowledge transfer which we found to be linked to improved team innovation.

The finding that learning from team members was not correlated with psychological safety was unexpected. Based on the literature, we expected psychological safety to correlate with both more teaching and more learning between teammates (Post C., et al., 2009). Since it was found that psychological safety is correlated with teaching teammates discipline specific knowledge, but is not correlated with learning from teammates, the relationship between knowledge transfer and psychological safety should be further examined. It is possible that students who reported poor psychological safety were afraid of teaching their teammates, but their teammates did not feel the same poor psychological safety, and hence were able to teach their peers. The former group of students would give a negative rating of psychological safety, but still learn from their teammates. The latter group would give a positive rating of psychological safety, but does not learn from their teammates. If this is the case, learning would not be consistently reported with good psychological safety but teaching still would.

4.3 Qualitative Part

One-on-one interviews were conducted with 11 students in the course. Interviews were 30-40 minutes in duration and participants answered a set of open-ended questions. Participants discussed their multidisciplinary capstone design experience. The responses were audio recorded. Students were asked questions about team dynamic, team communication, knowledge transfer, feedback, and innovation. They were also asked to give feedback for course improvement and to describe their experience as positive or negative with an explanation for their choices. Out of the 20 teams in the course, the data was collected from 11 teams, because all the students who attended
the interviews were from different teams. Hence, the data gave us a broad range of answers and a good coverage of student population.

**4.3.1 Qualitative Methodology**

The purpose of qualitative analysis is to draw conceptual understandings, in the form of categories and themes, from the abstract ideas captured in participants’ responses. Research constructs like innovation, psychological safety and etc. were identified to guide the research and analysis process. The objective of my research was to investigate factors affecting innovative behaviors in both implementation and creativity stages. With this broad approach, I was openly looking for categories to emerge from my data.

All interviews were recorded using a digital voice recorder and transcribed verbatim by the researcher. Interviews were transcribed partially after the initial investigation. All the coding and transcripts were done using the Microsoft word. Although software like NVivo™ are better suited for this purpose, the unfamiliarity with the software, time constraint due to the mix method nature of this research and cost constraints were among the reasons to choose Microsoft word at this stage of research.

To rigorously and systematically achieve the analysis objective, qualitative analysis procedures of coding and categorization of the data were conducted. This was followed by data interrogation to draw meaning and relationships from the categories and make the connection between themes.

We used descriptive and interpretative data analysis. The descriptive phase involved initial content analysis of the data like coding, categorizing and etc. (Patton, 2002, p. 463). The interpretive phase of analysis involved interrogation of the categories to make meaning and build conceptual understanding.
Each interview was analyzed completely using open coding techniques. Then we searched for patterns between the interviews that can be further explored. In qualitative method, the researcher is the instrument for analysis and outcomes will be the researcher’s interpretations. Throughout this process, I used iteration of data analysis to identify and prevent any biases I might have toward this investigation due to my participation and positive experience in multidisciplinary capstone.

4.3.2 Qualitative Results

The rationalistic and naturalistic approaches were used for data collection. Themes were developed by coding the data. We focused on and searched for relationship between psychological safety and innovation. There are other trends and correlations that we could have investigated with the data on hand, but considering the scope and time constraint, we limited our investigation to the mentioned categories. The relationship between psychological safety and innovation was chosen on the basis that we found a strong correlation between them in our quantitative results. Also our quantitative results show that psychotically safety is correlated with many other factors itself. Therefore, we coded our qualitative data for anything that was related to psychological safety and its effect on team innovation and performance. The following factors were the indicator of psychological safety: trust, comfort, ability to voice opinions, safe to take risk, safe to ask for help, not being rejected for being from different discipline, unique skills are valued and utilized, free and open communication within the team, and constructive feedback. We found a connection between psychological safety of the team and innovative behaviors. Here are some examples of emerging themes and categories that arose from our coding.

Unique Skills are Valued and Utilized:

“We were not able to get this design into prototyping stage without having a student from ECE “-(Electrical and Computer Engineering)-“. The knowledge that he was able to bring with problems
that would arise on the computer side, that arise from integrating the hardware and software together, allowed us to go forward in this project with the confidence that we could actually make it, versus if we were just Mechanical, we would have a huge section of knowledge missing that we would have to learn in addition to all the time that we already put in, which may have been too much, or just have to stop and scale back [...] to something at a lower level, not have gone for such an aggressive project.”

In this case unique skills of students are valued and utilized. Team members did not reject one another because of their different disciplines. They appreciated and trusted each other’s knowledge. All these psychological safety factors appear to lead to the project success and allowed students to implement their idea using their disciplinary knowledge. Furthermore, this is an example of positive effect on innovation at the implementation stage. The team of only mechanical engineers might have been able to come up with this creative idea but the implementation was not possible without the expertise of a non-mechanical disciple, in this case an ECE student. These students also mentioned that they learnt a lot form the ECE member during the integration process. Similar findings have been reported from eight of the eleven students involved.

**Free and Open Communication:**

“We were very respectful to each other’s knowledge. We were very logical in our decision making process. We made sure we heard all the opinions and then we decided. That is the whole point of having different disciplines. To be able to see the problem from different logical perspectives.”

Unique skills are valued and utilized because the team environment was open to different perspectives. There was an open line of communication which appears to build trust in the team. This indicates an environment in which students were all able to share their thoughts and opinions
and make a collective decision. This environment allows for open communication that can potentially lead to creative ideas from different perspectives. People did not feel left out because of the decision making process in place. This process encouraged and welcomed new ideas from different perspectives to be heard. Constructive feedback and communication was a key factor. This team experienced excellent psychological safety, which is facilitated by feedback.

The above-mentioned factors linked to high psychological safety of the team allowing the members to see the problem from different perspectives and to be creative. These factors could have potentially inhibited the creativity side of innovation by creating fear of failure and rejection in the team environment which would have discouraged people from different backgrounds to be able to bring their knowledge and expertise to the table. “We made sure we heard all the opinions” indicates that people were able to express their different perspectives. One of the team members said “I think we were more innovative because we took into account factors from mechanical and chemical processes”. This indicates that psychological safety of the team appears to be linked to innovation by enabling diversity of skills to play a role. In this case, the students were able to overcome any negative effect that functional diversity had on psychological safety and were able to exploit its potential benefits. The element of free and open communication was reported by nine of the eleven student involved.

**Lack of Trust:**

“There was no trust from the beginning. I was not sure about what they can accomplish and I ended up doing most of the project by myself. I think there was a lack of trust and also motivation. It was just not there from the beginning.”
The lack of trust, in this case, seems to lead to ineffective communication. It also prohibited the use of unique skill sets in the team. It is not clear whether the lack of motivation was a personal factor or it was due to the lack of trust from the team environment. Lack of trust made this team a dysfunctional team. Innovation was negatively affected in both creativity and implementation. In this study, we are investigating innovation that results from diversity. This team’s design still could have been innovative if one individual took the responsibility for the team. This team had little psychological safety, and that directly prevented them from working together to finish the project. Motivation was a contributing factor for psychological safety. This agrees with the theory of the team climate for innovation proposed by Anderson and West.

Since both a qualitative method and a quantitative method were used to investigate the relationship between psychological safety and innovation, method of data triangulation was used to increase credibility. Interviews provided support for our interpretation that psychological safety is important for team innovation.

The first source of data comes from the literature review which helped us establish the background research and the definition of the study. According to the literature, psychological safety predicts innovation. The second source of data comes from the Likert scale responses within the quantitative part that also found strong correlation between team innovation and physiological safety. Finally, the third source of data was the documented open-ended interview responses. It was evident from the interviews that psychological safety has affected the team innovation and performance both directly and indirectly.

Triangulation of data shows low psychological safety seems to decreases team innovation while high degree of psychological safety is linked to innovative behaviour. This result cannot be generalized and requires further exploration due to the sample size of this study.
The followings are the selected quotes from students’ responses and their relation and correlation with psychological safety and innovation.

4.3.2.1 Emerging Themes Related to Innovation

Although we only coded for any relationship between psychological safety and innovation, we discovered some other interesting themes while coding for the psychological safety indicators that also seem to have an effect on innovation. This section briefly reviews a few of these observations.

4.3.2.1.1 Different Perspectives

In literature, working effectively with people who define problems differently is stated as one of the global competencies for engineers (J. C. Swearengen, et al, 2002). The result of the interviews suggests that students in multidisciplinary capstone were able to gain this competency by working with students from other disciplines. A team of students with diverse educational backgrounds
pushed students to see the problems from different perspectives. 11 out of 11 students mentioned this while describing their multidisciplinary experience. For example, one Electrical and Computer Engineering student mentioned:

“I learned that there are different ways of solving an issue, I tend to look at all the problems as an ECE [Electrical and Computer Engineering] problems and identify ECE solutions for it. Because that's what I know and learned. These guys [Students from Mechanical and Engineering Science background] identified solutions that I would have never taught of. For example, I could not think of any way to stabilize this system without changing the frame, they [Mechanical Engineering Students] managed to stabilize this [UAV-Unmanned Aerial Vehicle] without changing the frame which is what made this design work.”

As mentioned by this student and others during the interviews, learning to see the problem from different lenses helped them to come up with new ideas and solutions. Seeing problems from different perspectives was constantly reported as a positive experience of multidisciplinary capstone.

4.3.2.1.2 Teaching Disciplinary Knowledge

Students reported that by teaching their disciplinary knowledge to other team members, they became a better communicator and more aware of their own assumptions. Communicating knowledge to people outside of one’s expertise is known as a vital skill at work environment (Van der Vegt & Janssen, 2003). Nine out of the 11 students reported that they learned by teaching another team member and that it was a positive learning experience. Two students found the teaching process was frustrating but still valuable. In their case, students were not matched properly to the required disciplines for the project. So they had to teach another team member from another discipline to do part of the project in their discipline. This was identified as one of the
problems with the multidisciplinary team. More strategies should be placed in students and project matching to assure that students are assigned to the projects that their disciplinary knowledge is required.

Being in a diverse team led to more communication and learning. Students reported that they became a better communicator by being aware of their assumptions as one participant describes:

“We [from mechanical engineering] had to explain the terminologies to these guys [from Electrical and Computer Engineering] ... I understood my assumptions when talking to other engineering students.”

“When I [Computer science] was explaining to Bob [Electrical Engineering], I realized my underlying assumptions .... They why questions that he asked made me think of new ideas ...”

Students in undergraduate multidisciplinary capstone became aware of their own biases as a result of trying to communicate their ideas to their teammates from other discipline. Not only the person who is teaching, but also the person who is learning will have a higher chance of coming up with new ideas as both do not have presumptions and both have a new perspective about their project. For example, two of the people I interviewed choose a project outside of their discipline because they wanted to learn something totally new and different. One mechanical student chose a financial related project and another mechanical student chose a project in mobile app development. Both of these students reported that they came with more diverse set of solutions in the idea generation phase of the project as they had a new sets of eye to the problems at hand.
4.3.2.1.3 Collaborative Learning

We already investigated apply/learn and teach interaction within the students. To better understand these interactions and the idea of collaborative learning, these interactions are depicted in Figure 3.

Figure 3 Knowledge transfer dynamics in multidisciplinary capstone design teams.

Students need to not only apply their knowledge but also to communicate their knowledge across the team by either learning or teaching it to achieve integration. In our interviews, 11 out of 11 students reported collaborative learning activities within their team. Students who had to constantly learn from each other’s and they had a high degree of internal communication reported more innovative behaviors and motivation level.

4.3.2.1.4 Student Motivation

Our interviews show that students’ internal motivation and excitement for the project was a contributing factor to innovative behaviors. Nine out of the eleven students who were interviewed indicated that they chose the multidisciplinary capstone over their departmental capstone because
the project, due to its multidisciplinary aspect, was more compelling to them. This initial interest and motivation for the project itself was found to improve the psychological safety of the team. On the other hand, the other two students reported that the lack of motivation led to less communication between the team members. This lack of motivation and communication prevented any possible innovative behaviors to arise from the potential diverse skill sets that were available to the team. Aside from the motivation and interest that came from projects with multidisciplinary nature, real world nature of these projects with the involvement of industry partners was another motivating factor for some of the students. Some of the students from the Faculty of Applied Sciences and Engineering, do not even have an option of doing industry based projects in their home department. This found to be a driving factor for students’ motivation. Motivation can also be related to team’s vision. Based on this data, motivation affected innovation in both creativity and implementation part by enabling communication and collaborative learning.

4.3.2.1.5 Value of Expertise and Skill Sets

I found during the interviews that in multidisciplinary capstone students feel responsible to be the best ambassador for their discipline, and hence they hold themselves accountable to present their best. For example, an industrial engineering student in a multidisciplinary team, is perceived as the industrial engineer expert and this really boosted their motivation to bring their best forward. At the same time, some students reported that this was challenging for them as they were the only person responsible for their discipline related problems. Overall, students reported that it was a very positive experience to represent their discipline in a team.

Students also repeatedly mentioned that integrating their functional diversity was crucial for producing an optimal final product:
“I think in a multidisciplinary team we were able to come up with a complete product. For example, as a mechanical student I never would have taken the human factor element into consideration in early design stages if we did not have an industrial engineering student on the team.”

4.3.2.1.6 Budget Limitation

Budget limitation was expressed as one of the barriers to be innovative by some of the students. Since I do not think that budget limitation is categorized as one of the team level factors and I consider it an external factor that cannot be controlled, I did not study budget limitation further. Although I agree that access to better facilities and having a sufficient budget for the project plays an important role in the implementation, I believe that these cost constraints exists in industry settings too and we never have unlimited budget. Therefore, I excluded this factor from my investigation.

4.4 Conclusion

Our results show that students rated themselves as very innovative in the multidisciplinary capstone. However, there are certain barriers regarding the knowledge transfer, communication, and psychological safety that can be addressed during the development of such a course. We found statistics that support the idea that feedback, knowledge transfer, psychological safety, and the multidisciplinary nature of capstone are positively correlated to innovation at the team level and/or at the individual level. We also found that psychological safety of the team has a strong correlation with innovation. Our results show that low psychological safety appears to inhibit innovative behaviors and high psychological safety appears to encourage innovation. Since this study was only based on self-reported data which introduce biases (Furnham, 1986), we decided to incorporate external assessments as a third party rating of innovativeness in the next study. This
study also informed factors like external and internal communication, support for innovation to be added to the list of survey measure. Since knowledge transfer was found to be correlated with innovation we developed collaborative learning measure to further investigate this relationship. Furthermore, since the result from this study was only based on the data from multidisciplinary students, we decided to survey monodisciplinary students as well to have a baseline for our comparison.
5 Exploratory Study

This study is an analysis of team-level factors affecting innovation in capstone student teams by comparing multidisciplinary and monodisciplinary courses. The potential that multidisciplinary capstone teams may produce more innovative designs was one of the motivating factors in creating the multidisciplinary capstone. By comparing these two groups, we can assess the performance of this newly introduced multidisciplinary framework on the basis of innovation. The monodisciplinary students in this case were teams of only mechanical students or only industrial students.

This study is an extended version of our first study to measure how innovative students are, in both multidisciplinary and monodisciplinary capstone, from students’, supervisors’ and clients’ point of view. Our study, investigates factors affecting innovation and their correlations. As we discussed in previous chapters, we have done an extensive research to determine which factors to include in this study. Our quantitative and qualitative results from first study informed the design of this study. Here are the latent and observed variables that we included in this study:

Innovation, psychological safety, collaborative learning, internal communication, external communication, vision, support for innovation from team members, support for innovation from supervisors, support for innovation from clients.

As mentioned before, there are other factors like student creativity, cost and time constraints and the nature of the project itself that can also affect innovation. But these factors are beyond the scope of this study. Therefore, we call this study a team level factors, as we are looking for factors at team level that can be improved rather than individual’s ability to be innovative and creative or external factors that cannot be controlled (e.g., the nature of the projects).
We have utilized online surveying, interviews and video recordings for data collection of this study.

5.1 Methodology

We asked the students who were taking the multidisciplinary capstone/Mechanical capstone/Industrial capstone at 2015-16 school year, a set of survey questions on innovation, psychological safety, collaborative learning, external and internal communication, vision, support for innovation from all parties, and element of team climate inventory. We examined the relationships between our measurements of these variables to understand the innovation in this new multidisciplinary capstone course compare to monodisciplinary one. The survey used Likert Scale responses to measure all the variables mentioned above. On top of the quantitative survey, we also used qualitative method of conducting interviews and video recordings for data collection. One team from mechanical capstone and one team from multidisciplinary capstone voluntarily participated in the qualitative portion of my study by letting me video record a few of their meetings with follow up interviews with each of the team members. They were compensated $30 individually for their participation. As we discuss in detail in the “Qualitative part” section, ten students were involved in the qualitative portion of the study.

Participation in both qualitative and quantitative part of this study was optional for students. We collected from 138 students. After cleaning the data only 124 responses were used for analysis. Here is the breakdown of the collected data with respect to their capstone courses:
Table 2 Statistics on the analyzed responses of the qualitative study.

<table>
<thead>
<tr>
<th>Course Category</th>
<th>Number of student participated</th>
<th>Number of students enrolled</th>
<th>Response Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIE 491 (Mechanical)</td>
<td>67</td>
<td>203</td>
<td>33%</td>
</tr>
<tr>
<td>MIE 490 (Industrial)</td>
<td>22</td>
<td>83</td>
<td>26%</td>
</tr>
<tr>
<td>APS 490 (Multidisciplinary)</td>
<td>35</td>
<td>89</td>
<td>39%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>124</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data scrubbing and analysis was completed using SPSS by:

- removing missing data,
- checking reliability of measures by calculating Cronbach’s alpha
- performing bivariate correlational analysis of all factors with each other
- performing Mann-Whitney test of comparison between two samples

5.2 Quantitative Part

In this section, I will discuss the type of data we are analyzing following with an explanation of appropriate statistical tests for this study. I will briefly explain how I validated this data and how was the data cleaning process. Then I will compare the two groups by using Mann-Whitney nonparametric tests, and subsequently by bivariate correlation with spearman pho test. In the end, I will explore the data from external examiners.

5.2.1 Type of Data

Data collected on a Likert scale is considered ordinal scale data. This means that it should not be modeled on the natural numbers (Wilcox & Keselman, 2003). Hence, parametric tests and operations such as taking the mean are inappropriate for this data (Allen & Seaman, 2007). For example, the mean relies on the measurements having additive properties. But the “value” of a Likert scale response is not as rigorously defined, and hence the distance between agree and
strongly agree is not necessarily a consistent interval, or mean the same as the difference between disagree and strongly disagree. Therefore, taking mean is inappropriate.

After an extensive search, we concluded to use median for our statistical analysis. The main reason for this decision was that the data is ordinal and we cannot assume normal distribution for the variables that we analyze. The median is generally considered the best measure of central tendency for ordinal data (Wilcox & Keselman, 2003). Therefore, we need to use nonparametric test to analyze our data.

5.2.2 Non-Parametric Tests

Because our data is ordinal and non-continuous, it is generally considered inappropriate to conduct statistical tests on it that assume that it is drawn from a distribution with particular parameters (e.g., a normal distribution). Therefore, we need to use nonparametric test for our statistical analysis.

5.2.2.1 Correlation

Kendall’s Tau and Spearman’s Rho are non-parametric tests for correlation analysis. Kendall’s Tau and Spearman’s Rho tests of association between two variables are used for statistical analysis with median and to compare ranked lists of data points. They test the degree to which the variables positively or negatively co-vary. We used Spearman’s Rho to be able to calculate the coefficient of determination a value which is not applicable to Kendall’s Tau. We also calculated all the correlations with Kendall’s Tau and all the correlations were consistent between these two tests.

For the sake brevity, in this thesis, we are presenting only the Spearman’s Rho test. This test replaces the values of the data set with their ranks according to their size, and then measures the covariance between the two data sets. This ranking removes skewed variables and is robust to outliers. Spearman’s rank-order correlation is the nonparametric version of the well-known
Pearson product-moment correlation. Spearman correlation assumes there is a monotonic relationship between the variables. A monotonic relationship is a relationship that does one of the following: (1) as the value of one variable increases, so does the value of the other variable; or (2) as the value of one variable increases, the other variable’s value decreases. The assumption of a monotonic relationship is less restrictive than a linear relationship. Spearman’s correlation coefficient, measures the strength of association between two ranked variables.

There are two methods to calculate Spearman's rank-order correlation depending on whether the data has tied ranks or it doesn’t. The formula for when there are no tied ranks is:

\[
\rho = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)}
\]

where \(d_i\) is the difference in paired ranks and \(n\) is the number of observations. The formula to use when there are tied ranks is:

\[
\rho = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}}
\]

where \(x\) and \(y\) denote the internal rankings (i.e., the ranking with respect to other observations of the same variable) of the observations for the two variables.

Both of these formulas are obtained from (Corder, 2014). In the literature and the outputs of the software that we used, \(\rho\) is usually denoted by \(r_s\). Hence, we report the Spearman’s correlation coefficients using the \(r_s\) notation.

Another analytics which is often reported is the coefficient of determination, \(r_s^2\), which is a measure of the proportion of variance in the ranks that the two variables share.

### 5.2.2.2 Comparison

To compare the score of innovation between the multidisciplinary and monodisciplinary, we used the nonparametric Mann-Whitney U test which is the nonparametric version of the t-test used for
normally distributed data. The Mann-Whitney U test is a test on the null hypothesis that two samples come from the same population against the alternative hypothesis that the population from which one sample is drawn tends to have larger values than the other population. This test was chosen because we are dealing with ordinal data that was collected with questionnaire and also our data does not represent a normal distribution. Also we have two independent samples that were tested at the same time and all of these criteria leads us to Mann Whitney U test. The Mann-Whitney U test is used to compare the differences between two independent groups (multidisciplinary and monodisciplinary) where the dependent variable (innovation) is ordinal, but not normally distributed. The Man Whitney test is calculated as

\[ U = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - \sum r_i \]

where, U is Mann-Whitney U test, \( n_1 \) is the size of sample one, \( n_2 \) is the size of sample two, \( r_i \) are the ranks of the observations from sample one, where ranks are calculated with respect to the union of both samples. For samples of more than 20, the value of U approaches a normal distribution and the hypothesis can be tested by Z-test. The value of U in Mann-Whitney test is the same as the Z value. Any of these values can be mentioned while reporting the data for this test.

5.2.3 Validation of Construct Measures

As we discuss before, Cronbach’s alpha is commonly used in psychology and social sciences to determine whether a set of survey questions are measuring the same idea, or “construct” (James, et al, 1984). It checks to see whether all the participants are answering consistently across the all the questions. For example, if a team had poor psychological safety, one can expect the participants to answer negatively on all the questions asking about positive experiences of psychological safety,
and a person on a team with great psychological safety would respond positively on all of those questions.

Therefore, Cronbach’s alpha was used to measure the internal consistency and reliability of each question measuring each construct. We measured Cronbach’s alpha for both multidisciplinary and monodisciplinary groups. In this section $\alpha_1$ is associated with multidisciplinary sample and $\alpha_2$ is associated with monodisciplinary sample. Measures of psychological safety ($\alpha_1=0.835$, $\alpha_2=0.691$), innovation ($\alpha_1=0.916$, $\alpha_2=0.962$), and collaborative learning ($\alpha_1=0.932$, $\alpha_2=0.925$), vision ($\alpha_1=0.954$, $\alpha_2=0.934$), external communication ($\alpha_1=0.894$, $\alpha_2=0.804$), internal communication ($\alpha_1=0.909$, $\alpha_2=0.925$), Support for Innovation ($\alpha_1=0.871$, $\alpha_2=0.925$), all exceeded the reliability criterion of $\alpha \geq 0.7$ except psychological safety for monodisciplinary team ($\alpha_2=0.691$). Since this value is very close to the threshold and many sources also report the threshold to be 0.6 (George & Mallery, 2003, p231) and these questions have been validated from the first study, we consider this alpha value acceptable. Table 11-25 in appendix C contain all the SPSS outputs for all the variables. Given that all reported Cronbach’s alpha values pass the reliability threshold, we are confident that each construct is being measured by its set of survey questions. Since these survey questions had good-high measures of internal reliability, we were justified to use the median of each student’s responses as a general score for each of these constructs.

5.2.4 Cleaning Data

We removed the missing values before conducting any analysis. We also searched for all the responses that were consistently the same and removed those from the study too as suggested in the literature (Rahm, 2000). For example, if students clicked on agree for all the questions, this means they were not paying attention filing out the survey. We recognized this by implementing reverse questions in the middle of regular questions. So student’s answers should have changed
from positive scale point to negative for the reverse questions. If there were no changes and all the answers were the same, then the datum was removed.

5.2.5 Test of Normality

Kolmogorov-Smirnov and Shapiro-Wilk tests were used to check if our data represent a normal distribution. It was shown that the answer to the psychological safety construct has a lower bond of true significant for normal distribution. But the rest of the constructs could not be represented by normal distribution and that's another justification for using non-parametric test for our analysis.

5.2.6 Multidisciplinary vs Monodisciplinary

To compare the score of innovation between the multidisciplinary and monodisciplinary groups we used the non-parametric Mann-Whitney U test as discussed before. The Mann-Whitney U test is used to compare differences between two independent groups (multidisciplinary and monodisciplinary) when the dependent variable (innovation) is ordinal, but not normally distributed. The Mann-Whitney test was performed in SPSS.

The sample size of multidisciplinary is 35 and the sample size of monodisciplinary is 89. The result of a Mann-Whitney test shows that innovation rating is higher in multidisciplinary sample compare to the monodisciplinary sample and this result is statistically significant ($Z=-2.18$, $p=.029<.05$ 2-tailed). Consistently, multidisciplinary students rated their teams more innovative than the monodisciplinary students.

This finding is consistent with the literature about the positive effect of job-relevant diversity on innovation in industry (Woodman et al., 1993). Job-relevant diversity is defined as “… the heterogeneity of team members with respect to job- or task-related attributes, such as function, profession, education, tenure, knowledge, skills, or expertise.” (Milliken & Martins, 1996; Pelled,
Eisenhardt, & Xin, 1999). The multidisciplinary team, in our study, had a job-relevant diversity with different disciplinary knowledge. Therefore, they were more prone to be innovative which is what we confirmed by our quantitative results. Literature also argues that broad range of expertise helps the team to solve complex problems and expose the team to variety of divergent perspectives and approaches which stimulates cognitive processes that lead to creativity (Perry-Smith, 2006). Hence, the higher level of innovation that our results show in the multidisciplinary team can be potentially due to their diversity of expertise and knowledge.

After comparing innovation between the two groups, we ran a series of Mann-Whitney tests to compare the rest of the constructs like psychological safety and support for innovation and etc. between the two groups. The results of the Mann-Whitney tests are summarized in table 3. Although many variables had different ranking between these groups, only the support for innovation from the supervisors was statistically significant to report.

From this data, it can be concluded that the support for innovation from the supervisors was significantly higher in multidisciplinary group than the monodisciplinary group (z=-2.256, p=0.025<0.05 2-tailed).
Table 3 Mann-Whitney test statistics for multidisciplinary and monodisciplinary students.

<table>
<thead>
<tr>
<th>Test Statistics</th>
<th>Innovation</th>
<th>Psychological Safety</th>
<th>Collaborative Learning</th>
<th>Internal Communication</th>
<th>External Communication</th>
<th>Vision</th>
<th>Internal Support for Innovation</th>
<th>Support for Innovation (Supervisor)</th>
<th>Support for Innovation (Client)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann-Whitney U</td>
<td>1183.00</td>
<td>1286.50</td>
<td>1475.00</td>
<td>1439.50</td>
<td>1245.50</td>
<td>1498.50</td>
<td>1542.50</td>
<td>1168.00</td>
<td>1344.50</td>
</tr>
<tr>
<td>Wilcoxon W</td>
<td>5188.00</td>
<td>5291.50</td>
<td>5391.00</td>
<td>5444.50</td>
<td>5250.50</td>
<td>2128.50</td>
<td>2172.50</td>
<td>5173.00</td>
<td>5349.50</td>
</tr>
<tr>
<td>Z</td>
<td>-2.180</td>
<td>-1.570</td>
<td>-1.381</td>
<td>-1.675</td>
<td>-1.833</td>
<td>-1.350</td>
<td>-1.086</td>
<td>-2.256</td>
<td>-1.219</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>.029</td>
<td>.116</td>
<td>.703</td>
<td>.500</td>
<td>.067</td>
<td>.727</td>
<td>.932</td>
<td>.024</td>
<td>.223</td>
</tr>
<tr>
<td>Exact Sig. (2-tailed)</td>
<td>.029</td>
<td>.117</td>
<td>.705</td>
<td>.502</td>
<td>.067</td>
<td>.729</td>
<td>.933</td>
<td>.024</td>
<td>.226</td>
</tr>
<tr>
<td>Exact Sig. (1-tailed)</td>
<td>.014</td>
<td>.058</td>
<td>.352</td>
<td>.251</td>
<td>.034</td>
<td>.366</td>
<td>.467</td>
<td>.012</td>
<td>.113</td>
</tr>
<tr>
<td>Point Probability</td>
<td>.000</td>
<td>.000</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
<td>.000</td>
<td>.001</td>
</tr>
</tbody>
</table>

As shown in table 4, mean rank of innovation and support for innovation from the supervisors was significantly higher for multidisciplinary students. Not only multidisciplinary students ranked themselves significantly higher in innovation, but they also indicated that they had higher degree of support for innovation from their supervisors.

Table 4 Ranks of Mann-Whitney test on innovation and support for innovation.

<table>
<thead>
<tr>
<th>Ranks</th>
<th>Group</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovation</td>
<td>1.00</td>
<td>35</td>
<td>73.20</td>
<td>2562.00</td>
</tr>
<tr>
<td></td>
<td>2.00</td>
<td>89</td>
<td>58.29</td>
<td>5188.00</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>124</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIN_Sup</td>
<td>1.00</td>
<td>35</td>
<td>71.63</td>
<td>2507.00</td>
</tr>
<tr>
<td></td>
<td>2.00</td>
<td>87</td>
<td>57.43</td>
<td>4996.00</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>122</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Now that we compared multidisciplinary and monodisciplinary groups by Mann-Whitney U test, it is important to report the effect size for this results aside from the statistically significance which was reported earlier. Reporting effect sizes gives a standardized measure of the size of the effect we observed, which can be used by other researched to compare our results to other studies.

The Effect Size can be calculated with this formula (Rosenthal, 1994):

\[ r = \frac{z}{\sqrt{N}} \]

Which N is the sum of sample sizes from both populations. We only calculated the effect size for innovation and support for innovation from supervisors which were statistically significant and were higher in multidisciplinary students.

For this survey of 124 students, the effect size was -0.19 for the innovation which is considered a small effect size (Cohen, 1988) and -0.2 for the support for innovation from supervisors which is considered small and moderate effect size. (Cohen 1988)

In our research, we wanted to know if students in multidisciplinary teams had lower psychological safety score due to their functional diversity. Because as mentioned in the literature review chapter, some studies have found that teams with people from different educational background experience have a lower psychological safety. The result of Mann-Whitney test shows that students in multidisciplinary teams actually had a higher psychological safety score. But this result is not statistically significance. This might be due to a small sample size that we have and partial responses from each team. Therefore, this answer to this question cannot be further explored.

5.2.7 Bivariate Correlation Analysis

We used SPSS to do a series of Spearman rank correlation between each two variables in both of our samples. The result is presented in table 5 for multidisciplinary students and in table 8 for monodisciplinary students. All the major correlation that was statistically significant is extracted
and reported after each correlation tables. If any correlation was weak (0-0.2) or it was not highly statistically significant, we did not report it in our result section.

Statistical significance of correlation coefficient value ($r_s$) depends on the number of observation. But how to interpret the $r$ value itself is highly dependent on the variables themselves and the field of study. Looking at many references, I decided to use this rule of thumb for my interpretation: We defined correlations in 0.3-0.5 as moderate and in 0.5-0.7 as strong and 0.7-1 as very strong. There are many categorizations in the literature about these categories. We chose the aforementioned categorization based on the field of study and the data set.

5.2.7.1 Bivariate Correlation for Multidisciplinary Sample
Table 5 Bivariate Correlations (Spearman’s Rho) for multidisciplinary students (*p<0.05, **p<0.01).

<table>
<thead>
<tr>
<th></th>
<th>Psychological Safety</th>
<th>Innovation</th>
<th>Collaborative Learning</th>
<th>Internal Communication</th>
<th>External Communication</th>
<th>Vision</th>
<th>Support for Innovation (Team Members)</th>
<th>Support for Innovation from Client</th>
<th>Support for Innovation from Supervisors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychological Safety</td>
<td>Correlation Coefficient</td>
<td>1.000</td>
<td>.579**</td>
<td>.699**</td>
<td>.270</td>
<td>.455**</td>
<td>.555**</td>
<td>.250</td>
<td>.432**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.000</td>
<td>.000</td>
<td>.117</td>
<td>.006</td>
<td>.001</td>
<td>.148</td>
<td>.010</td>
</tr>
<tr>
<td>Innovation</td>
<td>Correlation Coefficient</td>
<td>.579**</td>
<td>1.000</td>
<td>.509**</td>
<td>.129</td>
<td>.415*</td>
<td>.394*</td>
<td>.478**</td>
<td>.468**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.002</td>
<td>.460</td>
<td>.013</td>
<td>.019</td>
<td>.004</td>
<td>.005</td>
<td>.016</td>
</tr>
<tr>
<td>Collaborative Learning</td>
<td>Correlation Coefficient</td>
<td>.699**</td>
<td>.509**</td>
<td>1.000</td>
<td>.098</td>
<td>.426**</td>
<td>.648**</td>
<td>.296</td>
<td>.301</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.002</td>
<td>.576</td>
<td>.011</td>
<td>.000</td>
<td>.084</td>
<td>.079</td>
<td>.017</td>
</tr>
<tr>
<td>Internal Communication</td>
<td>Correlation Coefficient</td>
<td>.455**</td>
<td>.415*</td>
<td>.426*</td>
<td>1.000</td>
<td>.083</td>
<td>-.155</td>
<td>.138</td>
<td>.015</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.006</td>
<td>.013</td>
<td>.011</td>
<td>.636</td>
<td>.374</td>
<td>.429</td>
<td>.931</td>
<td>.739</td>
</tr>
<tr>
<td>External Communication</td>
<td>Correlation Coefficient</td>
<td>.555**</td>
<td>.394*</td>
<td>.648**</td>
<td>-.155</td>
<td>.521**</td>
<td>1.000</td>
<td>.095</td>
<td>.569**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.001</td>
<td>.019</td>
<td>.000</td>
<td>.374</td>
<td>.001</td>
<td>.587</td>
<td>.000</td>
<td>.011</td>
</tr>
<tr>
<td>Support for innovation (Team members)</td>
<td>Correlation Coefficient</td>
<td>.250</td>
<td>.478**</td>
<td>.296</td>
<td>.138</td>
<td>.234</td>
<td>.095</td>
<td>1.000</td>
<td>.188</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.148</td>
<td>.004</td>
<td>.084</td>
<td>.429</td>
<td>.176</td>
<td>.587</td>
<td>.280</td>
<td>.008</td>
</tr>
<tr>
<td>Support for innovation from clients</td>
<td>Correlation Coefficient</td>
<td>.432**</td>
<td>.468**</td>
<td>.301</td>
<td>.015</td>
<td>.526**</td>
<td>.569**</td>
<td>.188</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.010</td>
<td>.005</td>
<td>.079</td>
<td>.931</td>
<td>.001</td>
<td>.000</td>
<td>.280</td>
<td>.008</td>
</tr>
<tr>
<td>Support for innovation from supervisors</td>
<td>Correlation Coefficient</td>
<td>.293</td>
<td>.403*</td>
<td>.402*</td>
<td>.058</td>
<td>.295</td>
<td>.423*</td>
<td>.440**</td>
<td>.442**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.088</td>
<td>.016</td>
<td>.017</td>
<td>.739</td>
<td>.085</td>
<td>.011</td>
<td>.008</td>
<td>.008</td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
The following tables summarize the important and significant correlations from the multidisciplinary group data (Table 5). Table 6 shows the relationship between innovation and other variables.

**Table 6 Summary of statistically significant correlations with innovation from Table 5.**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Relationship</th>
<th>Statistically Significant</th>
<th>Statistically Highly Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovation and Psychological Safety</td>
<td>Positive Strong</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Innovation and Collaborative Learning</td>
<td>Positive Strong</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Innovation and External Communication</td>
<td>Positive Moderate</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Innovation and Vision</td>
<td>Positive Moderate</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Innovation and Support for Innovation (Internal-Within the team)</td>
<td>Positive Moderate</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Innovation and Support for Innovation from Clients</td>
<td>Positive Moderate</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Innovation and Support for Innovation from the Supervisors</td>
<td>Positive Moderate</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

A series of Spearman's rank-order correlations was run to determine the relationship between innovation and other factors included in our study. We found correlations between innovation and psychological safety, collaborative learning, external communication, vision, and support for innovation from all parties.

There was a strong, positive monotonic correlation between innovation and psychological safety, which was highly statistically significant ($r_s(35) = .579, p = .000<0.001$). The coefficient of determination is $(.579)^2$ which is 33.5%. This implies that psychological safety shares 33.5% of the variability in innovation. This result is aligned with our result from the first study that further substantiates the validity of our argument that teams with higher psychological safety are more inclined to be innovative.
This is also consistent with literature that members of teams that have trust and nonthreatening interpersonal climate can come up with more and diverse ideas since they are not worried about negative judgemental thoughts from others (West, 1990).

Our results confirm that team related behaviors with respect to psychological safety are consistent in industry and education. When psychological safety state of a team is high, unique skills and knowledge of team members can be used to produce innovation (Schulz-Hardt, Brodbeck, Mojzisch, Kerschreiter, & Frey, 2006). It is important to emphasis that this result does not say anything about causation and it is merely a correlation. Having said that, it has been consistent for both studies and with the literature. Therefore, it is a reliable result.

There was a strong, positive monotonic correlation between innovation and collaborate learning, which was highly statistically significant \( r_s(35) = .509, p = .002<0.01 \). The coefficient of determination is \( (.509)^2 \) which is 25.9%. This implies that collaborative learning shares 25.9% of the variability in innovation. In other words, the more students collaboratively work together to learn from each other, the more they rate themselves innovative. We were not able to get a correlation between collaborative learning and innovation in our first study and that was the shortcoming of the questions that were asked. The result of this study comply with literature on industry teams that suggests teams with high levels of cooperative learning are more likely than other teams to realize their innovation potential (Post et al., 2009). This is because the more communication and knowledge transfer will create a larger pull of information than individual knowledge.

A two-tailed test of significance indicated the there was a moderate positive relationship between innovation and external communication with people outside the team and that the result is statistically significant \( r_s(35) = .415, p = .013<0.05 \). The coefficient of determination is \( (.415)^2 \)
which is 17.2%. This implies that external communication shares 17.2% of the variability in innovation. In other words, the more students searched for advice and communicated with people outside of their team, the more innovative they rated themselves. This observation of multidisciplinary teams is consistent with the literature that suggest team diversity triggers communication with members outside of the team. In addition, this external communication leads to the incorporation of diverse information and border perspectives (Perry-Smith & Shalley, 2003; West, 2002). In the next section, you will see that there is no correlation between innovation and external communication for the monodisciplinary team. We believe that multidisciplinary students sought for more resources and feedbacks from external parties and this is potentially due to their diversity of skills and disciplines.

External communication leads to obtaining new knowledge and opens up new perspectives that can spark new ideas. Similar to our result, many studies found positive relationship between external communication and innovation (Ancona & Caldwell, 1992b; Andrews & Smith, 1996; Denison, Hart, & Kahn, 1996; Keller, 2001; Payne, 1990). It is important to mention their subject was industry teams and ours are teams in the context of education.

There was a moderate, positive monotonic correlation between innovation and vision, which was statistically significant ($r_s(35) = .394, p = .019<0.05$). The coefficient of determination is $(.394)^2$ which is 15.5%. This implies that vision shares 15.5% of the variability in innovation. Students who had achievable goals and valuable objectives for their clients and these objectives were understood and agreed by their team members, rated themselves more innovative. We were actually expecting this correlation between vision and innovation because it was discovered during our last year’s qualitative results as a form of motivation. Students mentioned that if they had the same understating and realization of objectives and those objectives were defined to be achievable, they would have been more motivated to be innovative. Our result is also consistent with the
literature that suggest teams with clearly defined objectives are more likely to develop innovative ideas (West, 1990). Literature also suggest that there is a positive link between vision and innovation (West, 1990; West & Anderson, 1996). Many other studies also mentioned that team member commitment to objectives can lead to innovative behaviours (e.g., Cardinal, 2001; Gilson & Shalley, 2004; Rickards, Chen, & Moger, 2001).

So far, we reported the correlation between innovation and psychological safety, collaborative learning, external communication and vision. Next, we will report our finding with regard to support for innovation and innovation.

As mentioned in the survey design, we applied the definition of support for innovation to our problem (West, 1990, p. 315). In our definition, internal support for innovation describes approval and practical support of teammates to introduce new and improved ways of doing thinks in their projects. If there is support for innovation from team members, unsuccessful trials to be innovative are more likely to be tolerated. Therefore, team members are more likely to take risks to implement new ideas. This argument has been supported in literature. (King, Anderson, & West, 1991; Sethi, Smith, & Park, 2001).

There was a moderate, positive monotonic correlation between innovation and support for innovation (internal-within team members), which was highly statistically significant ($r_s(35) = .478, p = .004<0.01$). The coefficient of determination is $(.478)^2$ which is 22.8%. This implies that internal support for innovation shares 22.8% of the variability in innovation. In other words, the more supportive the team members were toward innovative behaviors the higher they rated themselves to be innovative. This finding is consistent with the theory of team innovation by west et al. (West, 1990; West & Anderson, 1996). They also identified support for innovation to be linked to innovation.
Support for innovation from team members is very important. But in capstone design courses support for innovation from external examiners (i.e., clients and supervisors) is also a key. External examiners have the power and control over the students’ outcomes and assessments.

A two-tailed test of significance indicated the there was a moderate positive relationship between innovation and support for innovation from supervisors which is statistically significant ($r_s(35) = .403, p = .016 < 0.05$). The coefficient of determination is $(.403)^2$ which is 16.2%. This implies that support for innovation from supervisor shares 16.2% of the variability in innovation. Furthermore, there was a moderate positive monotonic correlation between innovation and support for innovation from clients, which was statistically significant ($r_s(35) = .468, p = .005$). The coefficient of determination is $(.468)^2$ which is 21.9%. This implies that support for innovation from client shares 21.9% of the variability in innovation. In other words, the more clients and supervisor encouraged students to be innovative, the more students rated themselves innovation. In literature, encouraging new ideas and rewarding them from authorities like managers and supervisors are linked to innovative behaviours (Amabile et al., 1996; Madjar, Oldham, & Pratt, 2002; Scott & Bruce, 1994; Shin & Zhou, 2003). Although the dynamic is different and these researches have been done on industry teams, we believe that there is incentive for people weather it is grade or raise in salary. People in authorities that oversee the team can influence the team behaviours significantly.

We were expecting a positive relationship between internal communication and innovation that did not exhibit in our results. This could be potentially because there are two category of internal communication. One for organizing meeting and logistics and another for sharing ideas. Our questions might have not encompassed these two parts or distinguished between the two categories. Since internal communication did not correlate with any other variables, the questions
that we used to measure this construct was not appropriate for the context of capstone and was unsuccessful of measuring this construct.

So far, we only reported the result of the correlation between all variables and innovation.

Table 7 summarizes the relationship that we found in between the variables themselves.

**Table 7 Summary of statistically significant correlations between the variables in Table 5.**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Relationship</th>
<th>Statistically Significant</th>
<th>Statistically Highly Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychological safety and Collaborative Learning</td>
<td>Strong Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Psychological safety and External Communication</td>
<td>Moderate Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Psychological safety and Vision</td>
<td>Strong Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Psychological safety and Support for Innovation from clients</td>
<td>Moderate Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Collaborate Learning and Vision</td>
<td>Strong Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Collaborate Learning and Support for Innovation from Supervisors</td>
<td>Moderate Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Collaborate Learning and External Communication</td>
<td>Moderate Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>External Communication and Vision</td>
<td>Strong Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>External Communication and Support for Innovation from Clients</td>
<td>Strong Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Vision and Support for Innovation from Clients</td>
<td>Strong Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Vision and Support for Innovation from supervisors</td>
<td>Moderate Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Support for Innovation Internal and Support for Innovation from Supervisors</td>
<td>Moderate Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Support for Innovation from Supervisor and Clients</td>
<td>Moderate Positive</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

A series of Spearman rank-order correlations were conducted in order to determine if there were any relationships between the variables in our survey.
Exploring the relationship between these variables was not the objective of our study but we will report these correlations and explore a few of them further. The reason for searching and analyzing the relationship between these variables is to find a better model that encompasses all the variables that effect innovation. For an accurate model, we need to know the interdependence and covarying of different variables. Each of these variables might have a direct and indirect effect on innovation through other factors. Therefore, to have a better understanding of correlation coefficient between each variable and innovation we need to also be aware of the relationship between that variable and other variables.

Psychological safety had positive correlation with collaborative learning ($r_s(35) = .579, p =0.000$), external communication ($r_s(35) = .455, p =0.006$), vision ($r_s(35) = .555, p =0.001$) and support for innovation from clients ($r_s(35) = .432, p = 0.01$).

There is a strong positive correlation between psychological safety and collaborative learning which is highly statistically significant ($r_s(35) = .699, p =0.000$). A high psychological safety score suggests that students felt heard in the team and their skill sets was valued and there was an open communication. These conditions may have enabled more learning and knowledge transfer in the multidisciplinary team. This is aligned with literature that state psychological safety is a potential predictor of team learning (Carmeli & Gittell, 2009; Edmondson, 1999; Kostopoulos & Bozionelos, 2011).

There is also a moderate positive monotonic correlation between psychological safety and support for innovation from clients which was highly statistically significant ($r_s(35) = .432, p = 0.01$). The more support for innovation from client, the higher psychological safety score for the team. This finding support the idea that support for innovation from the client can influence team member to feel safe, to take risk, and to communicate their ideas freely.
There is a strong positive correlation between psychological safety and vision which is statistically highly significant \( r_s(35) = .555, p =0.001 \). It appears that a team with high psychological safety state also has a clear vision of the project due to free and nonjudgmental communication which is a result of a psychologically safe team.

Collaborative learning correlate with external communication \( r_s(35) = .426, p =0.011 \), vision \( r_s(35) = .648, p =0.000 \) and support for innovation from supervisors \( r_s(35) = .402, p =0.017 \).

There is a positive strong correlation between collaborative learning and vision which is highly statistically significant \( r_s(35) = .648, p =0.000 \). Students who had better understanding and agreement of objectives, goals and outcomes of the design problem, also communicated more and had more learning and teaching interactions. Vision had strong correlation with psychological safety and collaborative learning which are also strongly correlated with innovation. Furthermore, vision itself is correlated with innovation. Therefore, I believe, vision has an indirect effect on innovation through other variables such as collaborative learning. Helping students to create the same vision for the project might be a key to more innovative behaviors.

The positive moderate correlation between collaborative learning and support for innovation from supervisors also indicates that supervisors play an important role to encourage communication and learning activities within the team which is essential not only for the team’s success but also for innovation.

External communication correlates with vision \( r_s(35) = .521, p =0.001 \) and support for innovation from clients \( r_s(35) = .526, p =0.001 \). These positive strong correlations, which both are highly statically significant, support the idea that if clients are supporting students for innovation, they appear to be more motivated to ask and seek for advice from external members. This also might
be interpreted as if clients helped students to find external subject matters themselves. Again, vision appears to have an influence over students’ communication which was predictable. Have clear and achievable objectives create motivation that will potentially spark more communications.

Support for innovation from team members has a positive moderate correlation with support for innovation from supervisor \((r_s(35) = .440, p =0.008)\). Since the same correlation does not exist for the clients, we can conclude that support for innovation from supervisors are more crucial and play an important role for students’ innovative behaviors. They have a greater effect on supporting students’ innovative behaviors compared to clients. The fact that supervisors usually have more interaction with students and they also have control over their final grades can potentially explain this correlation. The more students reported support for innovation within the team the more they also reported they had support for innovation from their supervisor. It appears that supervisors play an important role on motivating students and influencing them and initiating their actions.

There is also a positive moderate correlation between support for innovation from supervisors and clients \((r_s(35) = .442, p =0.008)\). This is a surprising correlation as supervisor and clients are matched to projects separately and without any pre-relationship. One way in which this correlation can be explained is that if one of these parties pushed for innovative ideas, whether it was the client or the supervisor, and the other one supported the action. If we assume that the relation between the client and the supervisor is a two-way relationship, then our supervisors can motivate the clients to be supportive for new ideas. This means that by informing our supervisor to push for more innovative ideas we might create a support system for students to be more innovative. Because, we do not have the same control over our clients.

5.2.7.2 Bivariate Correlation for Monodisciplinary Sample
Table 8 Bivariate Correlations (Spearman’s Rho) for monodisciplinary students (*p<0.05, **p<0.01).

<table>
<thead>
<tr>
<th>Psychological Safety</th>
<th>Correlation Coefficient</th>
<th>Psychological Safety</th>
<th>Correlation Coefficient</th>
<th>Psychological Safety</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Correlation</strong></td>
<td></td>
<td><strong>Correlation</strong></td>
<td></td>
<td><strong>Correlation</strong></td>
<td></td>
</tr>
<tr>
<td>Psychological Safety</td>
<td>Correlation Coefficient</td>
<td>1.000</td>
<td>.703**</td>
<td>.717**</td>
<td>.072</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>Innovation</td>
<td>Correlation Coefficient</td>
<td>.703**</td>
<td>1.000</td>
<td>.711**</td>
<td>.141</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>Collaborative Learning</td>
<td>Correlation Coefficient</td>
<td>.717**</td>
<td>.711**</td>
<td>1.000</td>
<td>.042</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>Internal Communication</td>
<td>Correlation Coefficient</td>
<td>.072</td>
<td>.141</td>
<td>.042</td>
<td>1.000</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>External Communication</td>
<td>Correlation Coefficient</td>
<td>.538</td>
<td>.225</td>
<td>.718</td>
<td>.042</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>Vision</td>
<td>Correlation Coefficient</td>
<td>.297*</td>
<td>.190</td>
<td>.234</td>
<td>.408**</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.011</td>
<td>.018</td>
<td>.046</td>
<td>.000</td>
</tr>
<tr>
<td>Support for Innovation (Team members)</td>
<td>Correlation Coefficient</td>
<td>.245**</td>
<td>.442**</td>
<td>.379**</td>
<td>.348**</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.036</td>
<td>.000</td>
<td>.003</td>
<td>.003</td>
</tr>
<tr>
<td>Support for innovation from Clients</td>
<td>Correlation Coefficient</td>
<td>.371**</td>
<td>.425**</td>
<td>.365**</td>
<td>.121</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.001</td>
<td>.001</td>
<td>.002</td>
<td>.000</td>
</tr>
<tr>
<td>Support for innovation from Supervisors</td>
<td>Correlation Coefficient</td>
<td>.237</td>
<td>.403**</td>
<td>.376**</td>
<td>.135</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.044</td>
<td>.000</td>
<td>.001</td>
<td>.000</td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level (2-tailed).

Spearman’s rho
A series of Spearman’s rank-order correlation was run to determine the relationship between innovation and other factors included in our study for the monodisciplinary team as well. The following tables summarize the important and significant correlations from the data from the monodisciplinary group. Table 9 shows the relationship between innovation and other factors.

Table 9 Summary of statistically significant correlations with innovation from Table 8.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Relationship</th>
<th>Statistically Significant</th>
<th>Statistically Highly Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovation and Psychological Safety</td>
<td>Very Positive Strong</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Innovation and Collaborative Learning</td>
<td>Very Positive Strong</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Innovation and Support for Innovation (Internal-Within the team)</td>
<td>Positive Moderate</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Innovation and Support for Innovation from Clients</td>
<td>Positive Moderate</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Innovation and Support for Innovation from the Supervisors</td>
<td>Positive Moderate</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Innovation has correlation with psychological safety ($r_s(89) = .703$, $p =0.000$), collaborative learning ($r_s(89) = .711$, $p =0.000$), support for innovation from team members ($r_s(89) = .442$, $p = 0.000$), support for innovation from supervisors ($r_s(89) = .425$, $p = 0.000$) and support for innovation from clients($r_s(89) = .403$, $p = 0.000$).

The correlation between innovation and psychological safety and collaborative learning is consistent with the literature and also our findings from the multidisciplinary teams. This was also expected as psychological safety and collaborative learning are important for innovative behavior regardless of monodisciplinary nature of the team. The result of Mann-Whitney test shows that multidisciplinary students had higher psychological safety and collaborative learning but these
results were not statistically significant. Therefore, we don’t have enough statistical results to draw any further conclusion or comparison between these two samples.

A two-tailed test of significance indicated there was a moderate positive relationship between innovation and support for innovation from supervisor which is highly statistically significant ($r_s(89) = .403$, $p = .000<0.001$). Furthermore, there was a moderate positive monotonic correlation between innovation and support for innovation from clients, which was highly statistically significant ($r_s(89) = .425$, $p = .000<0.001$). The more clients and supervisor encouraged students to be innovative, the more students rated themselves innovative. This result is consistent with literature and the results from the multidisciplinary teams. This shows that regardless of the combination and structure of the teams, support for innovation from external parties that have influence on the projects plays a great role on motivating or discouraging innovative behaviours. In other words, supervisors and clients can inhibit or facilitate innovative outcome by their feedback and communications. There is also a moderate positive correlation between innovation and support for innovation from team members ($r_s(89) = .442$, $p = .000<0.001$). This supports the idea that support for innovation, whether on internal or external level, is an important factor for innovation. This result is also consistent with the results of our first study, which implies that internal support for innovation is important for innovative behaviours regardless of the team’s combination.
Table 10 summarizes the relationship between the other variables.

**Table 10 Summary of statistically significant correlations between variables in Table 8.**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Relationship</th>
<th>Statistically Significant</th>
<th>Statistically Highly Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychological safety and Collaborative Learning</td>
<td>Very Strong Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Psychological safety and Support for Innovation from Clients</td>
<td>Moderate Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Collaborate Learning and Support for Innovation (Internal-Within the team)</td>
<td>Moderate Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Collaborative Learning and Support for Innovation from Clients</td>
<td>Moderate Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Collaborate Learning and Support for Innovation from Supervisors</td>
<td>Moderate Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Collaborate Learning and External Communication</td>
<td>Moderate Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Internal Communication and Vision</td>
<td>Moderate Positive</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Vision and Support for Innovation (Internal-Within the team)</td>
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<td>Support for Innovation (Internal-Within the team) and Support for Innovation from Clients</td>
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<td>Support for Innovation (Internal-Within the team) and Support for Innovation from Supervisors</td>
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<td>Support for Innovation from supervisors and Support for Innovation from Clients</td>
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There is a positive strong correlation between psychological safety and collaborative learning, which is highly statistically significant ($r_s(89) = .717, p =0.000<0.001$). This finding is consistent with literature and our results from the multidisciplinary group. This implies that having a psychologically safe environment is essential for collaborative learning regardless of the structure of the team. Therefore, implication for practice to improve psychological safety of the team that will be discussed in chapter 9 can be applied for both groups.

Many of these correlations have been discussed previously for the multidisciplinary group and many still hold for monodisciplinary group. Therefore, we will not explore them further. There reason that we have a lot of correlation in common between these two group, is that many of the variables included in this study are not strictly for teams with multidisciplinary nature. For example, the support for innovation from external parties, communication and learning activities is important for any team to be more innovative and it is not exclusive to multidisciplinary teams. Although our comparison results show that multidisciplinary students reported themselves to be more innovative and we believe this appears to be due to their functional diversity. I also discovered during my interviews that even the monodisciplinary teams have multidisciplinary natures. Although their disciplinary knowledge is not as diverge, but it is enough for collaborative learning to happen. For example, a team of mechanical engineering students can be comprised of one student from solid stream, one from energy stream and one from mechatronic steam or bio-engineering. As you can see, we have diversity even within our monodisciplinary teams. But the extent of this diversity and the nature of the projects themselves is higher for the multidisciplinary teams.
5.2.7.3 Partial Correlation

As mentioned earlier, the coefficient of determination shows the proportion of variance in the ranks that two variables share. We calculated and presented the coefficient of determination for each factor that had a correlation with innovation. These factors have overlap with each other’s. For example, the 33.5% variability that psychological safety (in multidisciplinary sample) shares with innovation has overlap with other factors that contribute to psychological safety. We used partial correlation to calculate the variability of each of these construct with innovation while controlling for all the other variables. A series of table in appendix C-section 9.3.4 shows the result of this partial correlation. The correlation between each variables and innovation has been calculated while controlling for the rest of the variables. If we add up the variability from all the constructs that we included in this survey, we get 33.64%. This means that all the variables that is explored in this study only account for 33.64% variability in innovation. There are many other factors like student’s capability, team combination, project itself and etc. to just name the few.

5.2.8 External Assessment

The data we presented so far have been self-reported. Single source of data can cause methodological problems (Lindell & Whitney, 2001; Williams & Brown, 1994). Self-report data can also be biased (Kurtzberg, 2005). Therefore, in this section we assess innovation from external examiners. The results of this section have been published in Proc. 2016 Canadian Engineering Education Association (CEEA16) Conference with the title of: “Are multidisciplinary design capstone’s students more innovative than monodisciplinary ones?” (Balouchestani & Behdinan, 2016).

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 (Keller, 2001 & Bunderson, Sutcliffe, 2002). 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 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. Both the supervisors and the clients are involved in grading in monodisciplinary capstone. In multidisciplinary capstone, supervisors grade the students and clients only give feedback to the students by filling out the rubrics. We used the rubrics whether it was used toward grading or giving feedback.

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.

We collected data from supervisors and clients from the assessment rubrics they filled out during the school year. As discussed before, innovation is commonly defined as creativity, which is the generation and refinement of novel ideas and solutions, implementation, which is the creation of
a physical product or design, and usefulness, which is how valuable and functional the product or
design is (Paletz, Schunn, 2010 & West, 2002 & West, Farr, 1990). To account for both creativity
and implementation, we use rubrics from both the first semester and the second semester. This
ecompasses 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 capstones 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.

5.2.8.1 Diversity in Alternative Designs

Figure 4 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.
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 multidisciplinary groups received a full mark (4 out of 4), while only 35.16% of monodisciplinary teams received a full mark. The result of a Mann-Whitney test for Creativity also indicated that multidisciplinary students were more creative than monodisciplinary (Z=-4.231, p=0.000<0.001 2-tailed) and this result is statistically significant. The result for the creativity assessment is statistically significant and the effect size is calculated to be -0.52 which is considered large effect size (Cohen, 1988).

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 suggests 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 multidisciplinary groups and only 8.58% of the monodisciplinary 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 multidisciplinary 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.

5.2.8.2 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 5 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 5 Quality of design prototype scores for multidisciplinary and monodisciplinary capstone teams from external examiners.

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 multidisciplinary 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 in multidisciplinary teams.

A Mann-Whitney test also indicated that multidisciplinary group had better implementation than the monodisciplinary group (Z=-1.670, P=0.095). But this result is not statistically significant. Not only this result is statistically insignificant, but also the effect size is calculated to be -0.2 which is considered between small and moderate effect size.

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 was 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. The result of this quantitative analysis shed some lights on the performance of multidisciplinary courses around innovation. It appears that multidisciplinary students are coming up with more diverse ideas and they are more creative perhaps due to their functional diversity. It also appears that multidisciplinary students are better at the implementation stage. However, this result is not statically significant and requires further investigation.

5.2.9 Structural Equation Modeling

So far, all of our results were based on correlation and correlation does not mean prediction or causation. To take our result one step further, we originally wanted to do a regression analysis. But since our independent variables are also correlated, we cannot use regression analysis. Regression models are additive and not relational. Additive means, we cannot account for the relationship between the dependent variables who are predicting the outcome. Measurement errors are also not taken into consideration with regression models.

This is one of the complications of studying innovation and factors affecting it as the factors themselves are correlated. Our research shows that for condition we have between our variables Structural Equation Modeling (SEM) is the best approach to study causation. The model can incorporate interdependence of variables and can also account for same source data errors. We developed a structural equation model through AMOS software but because we have many observed variables for each construct, our sample size is very small to run the model. Furthermore,
for an SEM model to be reliable, many sources indicated that there must be more than 300 data points. For the above mentioned reasons, we were not able to complete the SEM analysis for factors affecting innovation. If this survey can be conducted over the coming years, over the time the collection of these data will be sufficient for any further prediction or causation by an SEM.

5.3 Qualitative Part

Our quantitative results consist of video recording from two teams, one from multidisciplinary and one from monodisciplinary. This was followed by one on one interviews of team members at the end of the year. Our qualitative method for analyzing the interview questions is the same as our approach for our preliminary study which was discussed in detail in section 4.3.1. The purpose of qualitative analysis is to draw conceptual understandings, in the form of categories and themes, from the abstract ideas captured in participants’ responses. Research constructs like innovation, psychological safety and etc. were identified to guide the research and analysis process. The objective of my research was to investigate factors affecting innovation behaviors in both implementation and creativity stages. With this broad approach, I was openly looking for categories to emerge from my data.

Video recording observation was mainly focused on two stages of idea generation in the first semester and implementation in the second semester. The observations from video recordings are limited to these two teams and cannot be generalized as there are many contributing factors to these results. These video observations served as primary data for us to better come up with interview questions and see the dynamic of the teams. This set of data mainly served as an observation tool.
5.3.1 The Multidisciplinary Team

Originally the plan was to compare the multidisciplinary and monodisciplinary teams from the interviews and video recording. But, after recruiting the teams, it was revealed that the mechanical engineering team is not only a capstone team in mechanical engineering but is also part of the international capstone. This violates our assumption about single disciplinary nature of this team as they were collaborating with other people around the world. Since the nature of international capstone is very different and out of scope for this study, we analyzed their video recordings and interviews separately and published our result in Proc. 2016 Canadian Engineering Education Association (CEEA16) Conference with the title of “Benefits and barriers to international collaboration for capstone design course” (Balouchestani, Zhu, & Behdinan, 2016).

Since comparison was not appropriate, we analyzed and focused only on the multidisciplinary team. In this section, we focus on the preliminary results that emerged from qualitative analysis of data obtained from one multidisciplinary team. The results of this study have been published in Proc. 2016 Canadian Engineering Education Association (CEEA16) Conference with the title of “A Qualitative Study of Team Level Factors Affecting Innovation” (Balouchestani, Zouda, & Behdinan, 2016).

We particularly examine factors that potentially affected innovation. The multidisciplinary team is composed of six members: one member from mechanical engineering, one from industrial engineering, one from electrical engineering, and two members from the engineering science program in which one member had a focus on electrical and computer engineering and one had a focus in computer science. As mentioned in our introduction section, innovation here is defined as the ability to develop creative ideas and implement them. In this research, innovation was self-evaluated by team members (based on our definition). To examine factors that might have affected
innovation in this multidisciplinary team, we collected data using naturalistic and rationalistic approaches (Guba & Lincoln, 1988). While the former allows the emergence of themes and theories, the latter is more predetermined and aims at examining pre-existing ones. Rationalistically, we used the 15 team-based innovation-related factors developed by Hülsheger, Anderson, & Salgado (2009) as the base for data collection, and as a main goal for data analysis. This was on top of all the other factors that we included in our survey. These factors are: job diversity, background diversity, task interdependence, goal interdependence, team size, team longevity, team vision, participative safety, supportive environment, task orientation, cohesion, internal communication, external communication, task conflict, and relationship conflict. Naturalistically, we collected data that allowed the emergence of unexpected situational outcomes. We used multiple methods for data collection as a means for triangulation to increase trustworthiness, and to provide different insights into the study (Norman K. Denzin, 2000). Data collection used the following methods:

Semi-structured interviews: to allow students to express how they experienced innovation in their team, and to explore innovation-related factors, we conducted semi-structured interviews with the six team members. The interviews took place at the end of the project, and they lasted on average for about 45 minutes.

Video recordings: The team was video recorded five times while working on the project (between September and March). The video recordings varied in length from 20 minutes to almost an hour. Video recordings were used as a means to take field-notes while allowing the team to work relatively naturally with minimal interference from the researcher. Data from the videos are used to increase trustworthiness and to provide deeper insights into team dynamics.
For data analysis, we used the initial developed codes while combining Charmaz’ (2006) Constructivist Grounded Theory (Charmaz, 2006): new codes were developed and then categorized to allow emerging of themes and theories. Main emerging codes, categories and theoretical themes are discussed in the following section.

The results of interviews along with the video recordings show that these five factors hindered or facilitated innovation in this multidisciplinary team: multidisciplinary knowledge, team vision, the effect of supervisor, the effect of client and industry partner, and team size. We discuss each of these thematic areas in the following sections.

5.3.1.1 The Effect of Multidisciplinary Knowledge

Literature suggests that multidisciplinary teams tend to have low psychological safety scores because of their knowledge diversity. Low psychological safety negatively affects team’s collaborative learning and efficiency; consequently, it negatively affects innovation (Edmondson A., 1999). However, other literature indicates that having diversity in education, skill and knowledge leads to innovative behaviour as it allows spaces for the negotiation of different perspectives (Michael A. West, 1996). Our quantitative results show that multidisciplinary students were rated higher than monodisciplinary students by external examiner about their innovation.

When analyzing the data, we found that coming from different disciplines allowed team members to confidently express their ideas and successfully implement them in multidisciplinary team. Four sub-factors seem to have enabled this team to effectively express and use their disciplinary skills, knowledge and expertise to support innovation. These sub-factors are honesty about self-capability, trust in other’s expertise, appreciation of different skills, and patience while co-learning.
From the very beginning team members were self-aware of their expertise, and they clearly and explicitly expressed what they can or cannot achieve. As one participant framed it:

“At the very first meeting we told each other about our strengths and weaknesses, both technical and personal, and this really helped us through the project because we knew who is capable of what.”

Literature suggests that appreciating each other’s skill sets has a positive effect on a team’s ability to communicate their ideas. In this team, members seemed to also appreciate each other's’ varied skills and knowledge, and the different perspectives and inputs brought by diverse members. This was also evident from the idea generation meeting which was video recorded. As a couple of participants mentioned:

“I used to see any problem as an ECE [Electrical and Computer Engineering] problem but these guys helped me to have different perspectives now.”

“The knowledge of computer science person really helped us with implementation.”

“The industrial person was very knowledgeable of human factor, heuristics, usability test and what statistic to use, these are the things we never touched before. It was very interesting and eye opening for me with an electrical background.”

The honesty and appreciation between team members seem to have created a recognizable level of trust and confidence in each other's expertise, which seem to enhance their psychological safety, and consequently their tendency to express their ideas and implement them. Here are three quotes from different participants:

“We trusted each other with our skill sets and knowledge from the beginning.”
“I trusted that they [Team member] can deliver.”

“Although we got the resources and hardware late from our client we were able to manage to get a working prototype for the showcase and I think our showcase and implementation was really good since we had many people with great technical expertise on the team.”

Besides building trust between team members, patience and willingness to invest time and effort seemed to allow them to construct a positive and supportive team environment. This tended to reduce interpersonal conflict, a factor that is argued to affect innovation negatively (M. A. Cronin, 2007):

“We spent a lot of time developing team norms and rules and at the end it paid off and we were able to accomplish the task without any conflict.”

“We were very good at handling disagreement and opposing ideas because of the team norm that we created at the beginning.”

“Having had to explain myself to other people was hard at the beginning, you know the terminology and stuff like this, but I learned to do it and now that I think about it, it was a good learning experience.”

Team members’ willingness to invest time and effort could be tied to other important factors that affect innovation. These factors are team vision and task orientation. The willingness to invest time and effort was also observed during the video recording as students were meeting every week constantly for few hours to work together and discuss the progress of the project. There was a consistent communication within the team from all team members.
5.3.1.2 Team Vision

Having a common and shared agreement about the main goals of the project and the quality of the work are argued to be positively linked to team innovation (Tushman & Nadler, 1986). In this team, students seemed to have a clear and common understanding of the project objectives. Here are a couple of examples:

“We all wanted to do well on the project, but at the end it was not for the grade, we really wanted to see it working ... prototyping was the objective from the beginning and everyone knew it.”

However, in this project, there seems to be two interrelating factors that have led to a common vision: the nature of the project and the self-selection. The project required a physical prototype to be built and tested. All students have reported that they were excited about prototyping and the challenges it brings. Hence, everyone’s expectation was to get to the physical prototype and be able to test it by going through iterations. Here are a couple of examples:

“I looked at the list of all capstone projects and this project sounds very interesting to me, that’s why I choose to do the multidisciplinary capstone.”

“None of my group projects has been in this scale before...I was so motivated to do something special.”

“Now I have something to show in my resume... this is my final and biggest project and I want to have pride about it.”
5.3.1.3 The Effect of Supervisors

There are strong arguments that supervisors and managers, in industry, can greatly facilitate or hinder team innovation by the type of their support and feedback (West M. A., 2002). Supervisors and directors are encouraged to be explicit about expecting novel ideas, from team members, and to provide practical support to these novel ideas (Martins & Terblanche, 2003). In addition, and as mentioned earlier, rewarding creativity and providing spaces for risk taking tend to highly support innovation (Herbig & Dunphy, 1998 & Paletz S. B. F., 2010).

In this team, the supervisor played a positive role by supporting creative ideas and leaving the scope open for the team at the initial stages. Then, he appropriately helped the students to move from the abstract ideas to the practical ones by narrowing down their ideas and then applying those ideas. This supporting role played by the supervisor was explicitly appreciated by all team members, and tended to allow them to enact innovation. Here is an example from one team member:

“Supervisor left it very open at the beginning and then appropriately helped to converge our idea “

The supervisor also enabled innovation by fostering inclusiveness. He encouraged all students to express their ideas, and more importantly, he knew how to engage them in discussions. Here, not only did the supervisor enhance psychological safety but he also facilitated internal and external communication. He facilitated internal communication by providing a safe space for unheard voices, and external communication by having regular meetings with constructive feedback. There are strong arguments that the numbers of team meetings and internal communications are positively associated with team innovation (Martin Hoegl, 2004). As one participant nicely put it:
“During our weekly meeting he [the supervisor] made an effort for everyone to contribute to the discussion. He knew who was energetic and animated and tried to get everyone to talk and contribute. This opens the space for ideas to come forward.”

“We mostly got positive feedback like ok here is what you guys are working on have you tried this and that.”

Providing constructive feedback by not only critiquing weak points, but also focusing on positive sides and areas of improvement tended to open gateways for moving forward with implementation. This approach has been known as feedforwarding, and is argued to have a very positive effect on team dynamics and innovation (Sadler, 2010). Hence, the supervisor influenced the team positively in both stages of innovation which are creativity and implementation.

5.3.1.4 The Effect of the Client (Industry Partner)

The client played contradictory roles in supporting innovation. On one hand, he/she provided spaces for novel ideas to be developed at the grass root, without enforcing or dictating predetermined ones. On the other hand, not being able to provide the required hardware to the team inhibited their implementation. This was echoed by every student in the team, for example:

“Hardware delivery was delayed which made the technical difficulty in the team, you know there are different software depending on what type of hardware you get and we simply could not start till the hardware arrived.”

“As student with limited time frame it was hard to wait for things, getting any information, code, hardware was very challenging.”
It is not surprising that the power relation has a huge impact on team innovation. However, the availability of external resources also seems to be a crucial factor for innovation. External resources not only affect implementation, but they can also interrupt the design process and the flow of novel ideas, which would negatively affect innovation.

After these results, we further investigated our data from the first study to find any relationship between the client and innovative behaviors and team outcome. Our results show that the two students (teams) who had pre-existing relationship with the industry partner, reported high motivation of team member and no conflict or lack of communication. Pre-existing relationship of students with the client from companies they interned for, prevent possible negative affect on team innovation. Regardless of this pre-existing relationship, the support of the industry client appears to play an important role in innovative outcome.

5.3.1.5 Team Size

Capstone projects with a multidisciplinary nature usually have broader scopes than monodisciplinary ones. The broad scope of multidisciplinary capstone demands more students to be involved. Although bringing many students from different disciplines may allow spaces for innovation, increasing team size should be correlated with the time to see positive effects on innovation. In capstone, the eight months’ period of the project is considered relatively short to build relationships and set norms among members of a team that is larger than 4-5 students. There is tension between the benefits of multidisciplinary aspect of the team (translated into larger team size) and the time required to facilitate positive relationships and support innovation. Members of this relatively large capstone team faced difficulties in coordinating team meetings and regulating their internal communication. These difficulties were expressed by many team members:
“It was hard to get things done during team meetings with 6 people and 6 different perspectives!”

“The communication between 6 people was very challenging since we had other courses too.”

“During prototyping we ended up dividing in the team to two smaller teams.”

“To have a large team you have to have existing relationships.”

As discussed earlier, the challenge of coordinating internal communication seems to have been balanced by the regular meeting set by the supervisor and the efforts team members were willing to invest in their project.

5.3.1.6 Conclusion

Factors like trust, a shared vision, and similar expectations across the team enabled creative ideas to flourish from diversity in this multidisciplinary team. Since the absence of trust, shared vision and expectations inhibit innovative behaviors, it is essential for course coordinators and the teaching team to encourage an open discussion between team members about these factors and facilitate discussions through various workshops or supervisors’ internal meetings. Setting rules and team norms prevented interpersonal conflicts from happening within this team.

Although having a team of students with diverse skill sets enables creative ideas to come forward, it is important to create a culture of innovation that would support and reward student’s innovation. In this team, the supportive supervisor played an important role. Also, providing resources played a great role during the implementation side of this project that affected innovation. In my opinion, the absence of any of the above-mentioned variables will lead to a dysfunctional team.
5.3.2 Emerging Themes Related to Innovation

After analyzing the interviews and video-recording for multidisciplinary and monodisciplinary team, I realized that there are some finding that are repeated from last year. Therefore, I looked at my data from last year and this year to see if I can find any new themes and categories.

Innovation in design spine and design iterations are the two new categories that emerged from the data as it will be discussed in detail in the following sections.

5.3.2.1 Innovation in Design Spine

During the interviews I asked students about their capstone experience and their innovation from their perspective. Whether they rated themselves innovative or not, there was something common in all the responses that seems to greatly affect innovation and I call it the atmosphere for innovation. Many students accepted that they could have been more innovative in capstone as it was an open ended project, but since they were not encouraged to be innovative before, i.e., in the last three years of their undergraduate studies, it was not the norm. Students have to be reminded to be innovative and be rewarded for their innovative behaviors. Otherwise, they go through their design spine from first year to third year and they are not trained to be innovative. The students also mentioned that they were less motivated about engineering design in their 4th year compare to 1st and 2nd year. Therefore, I believe, incorporating multidisciplinary work or culture of innovation in early design spine is very crucial as students’ motivation level is higher. Although the space was open for innovation, the state of mind was to follow a series of steps like assignments.

I believe that we can’t expect students to come to their 4th year and all of sudden be innovative and creative if they have not been trained, encouraged or rewarded for innovative behaviors before.
Therefore, for students to realize the full potential in their capstone design course we must have a culture of innovation in our design spine that encourage creativity and tolerate failure.

5.3.2.2 Design Iterations

Going through iterations has been shown in literature to flourish innovative ideas. Experimentation and iteration are important for innovation. Because when we are looking to solve a problem, the solution needs to be tested to see how well it solves the problem or creates value, and then refined to increase that value (Wright, Skaggs, Fry, Howell, & West, 2010).

Combining the interview results from this year and last year, I came to the conclusion that students believed if they had more time to go through design iterations, they could have been potentially more innovative. When asked how do you think your team could have been more innovative, many mentioned that if the deadline was pushed into first semester so there was more time in second semester to go through the design iterations, they could have potentially been more innovative. This type of feedback from students was consistent across multidisciplinary and monodisciplinary. Therefore, although the idea generation phase is important for creativity, shortening it and adding time for more iterations and implementation might be a way to improve innovation via the implementation side of innovation.
6 Implication for Practice

The aim of my research was to explore innovation and factors effecting innovation in the multidisciplinary capstone design course. The nature of this research was exploratory, and hence no strategy has been implemented based on its results. Therefore, the implications for practice in this section are solely my personal suggestions based on my observations.

Informing Supervisor and Client

Our quantitative results show that support for innovation from supervisors and clients has a strong positive correlation with innovation. Furthermore, support for innovation from clients and supervisors has a positive correlation with support for innovation from team members. In other words, the students who felt strong support from their clients and supervisors, rated themselves more innovative and they also were more supportive in their groups for innovative behaviors. Therefore, we should inform supervisors and clients about how crucial and influential their feedback is to achieve innovative behaviors. We should encourage our supervisors and clients to be supportive of students and to tolerate unsuccessful trials.

Peer and Self-evaluation and Assessment

In our research, we repeatedly found a strong positive correlation between psychological safety and innovation. Therefore, improving teams’ psychological safety can potentially improve innovative behaviors and can lead to teams’ success. To improve psychological safety of the teams, I suggest incorporating peer and self-assessments into the course. As example of such a platform is Team Effectiveness Learning System (TELS) that was developed by Patricia Sheridan at University of Toronto (Sheridan, Evans, & Reeve, 2012). TELS provides students with peer-assessment and self-assessment and feedback related to teamwork. TELS also provide reports for supervisors and external examiners to have better understanding of the team dynamics for the
teams they are supervising. TELS help both students and supervisors to identify potential problems and conflicts at early stages and take actions to resolve them.

**Faculty Expert Zone**

Our results show positive correlation between the support for innovation from both supervisors and clients and innovation. Furthermore, our research shows that there is a positive correlation between innovation and external communication. In other words, the more students communicated with experts from outside their team (not the supervisor or the client) the higher they rated themselves to be innovative.

I believe new initiatives like faculty expert zone, can be beneficial to assist and initiate external communication by providing a network of support. The faculty expert zone is proposed by Engineering Design Education Group (EDEG), which is chaired by NSERC design chair. The goal of faculty expert zone is to get on board all the areas of expertise from across the faculty. Student can seek help and guidance from different engineering faculties.

**Constructive and Systematic Feedback**

Our quantitative results from the first study and qualitative results from the second study both show positive correlation between feedback and innovation. Our research informs educational institutions on how their feedback and input as a superiors and faculty advisors plays a role in innovation. The feedback either provides support for innovation, or limits students and imposes constraints. The same applies for the client’s feedback. Giving feedback is one of the important role of supervisors and clients. But the quality and the method of giving feedback can have a positive or negative affect on innovation and team’s success. As mentioned in our qualitative study, constructive feedback can play a positive role in team’s success and in creating motivation.
Constructive feedback can be in the form of pointing out what is not working with the design or what they have done right and what are the next steps they need to take. Although this seems very trivial, many supervisors and clients do not give constructive feedback. Unfortunately, many managers in the industry also forget to provide constructive feedback. Therefore, debriefing and informing supervisor and clients about how to effectively give a feedback is another important implication for practice.
7 Conclusion

We explored innovation and factors affecting innovation in a multidisciplinary capstone design course. This research consisted of two major studies. Both qualitative (i.e., one on one interviews and video recordings) and quantitative methods (i.e., online survey) were used for data collection.

From our first study, we found statistics that support the idea that feedback, knowledge transfer, psychological safety, and the multidisciplinary nature of capstone are positively correlated to innovation at the team level and/or at the individual level. Our qualitative results show that low psychological safety appears to inhibit innovative behaviors and high psychological safety appears to encourage innovation.

From our second study, we found statistical results supporting the idea that psychological safety, collaborative learning, external communication, vision, support for innovation from team members and support for innovation from client and supervisor are positivity correlated with innovation. We also found correlation between these variables with interesting implications.

We found that external examiners rated multidisciplinary student more innovative both in creativity and implementation element. Our research shows that diverse skill sets of multidisciplinary teams enable creative ideas to come forward in these teams.

The positive correlation between support for innovation from client and supervisor, vision and psychological safety was further confirmed by our qualitative results.

Our research provides data-driven insights for development of an effective multidisciplinary capstone design course which can be used by course coordinators to accordingly plan for team formation, project matching and creating an environment of support. Providing workshops and support from the faculty to guide students through this journey, peer evaluation on top of clients’
evaluation and supervisors’ evaluation, and constructive feedback are examples of further actions to be taken. Our results shed light on how to prepare an environment where innovation can flourish from the advantage of functional diversity.

7.1 Limitations

Our analyses, in this study, were limited by the sample size. This study has the error of non-observation which is the differences between the statistic calculated and the true parameter of the population. This means that the sample did not include all students in the capstone courses. Therefore, the analysis that requires opinions of all members of teams were impossible to complete. The team-level measures of innovation were based on only some of the students’ perceptions, and not on an aggregate of the ratings given by all the students in the team. Also these partial responses from each team prevented any further investigation and research to be completed between teams. This type of investigation will be essential and required for any further research directions.

Based on my extensive research for the ordinal data sets, which we studied in this research, the median was the best representative and way of calculation. The results may vary if we change the method of measurement. I did not assume normal distribution while interoperating the data. My interpretation and methodology is limited to my assumption of non-normality of these data sets.

These results are also biased by self-selection of students into multidisciplinary capstone design course. We do not have any information on whether more creative and innovative individual choose to do the multidisciplinary capstone course. Another major limitation is the use of surveys instead of a more direct measurement method.
Our analysis from the results of external examiners is also biased to the assessor’s understanding and perception of the provided rubrics. The same bias exists about student’s perception of innovation.

### 7.2 Future Research

This exploratory research can be a guide for finding further areas to explore with regard to innovation and multidisciplinary education. Identifying the challenges that students face in multidisciplinary environment will lead to the discussion on how to tackle these challenges.

Further analysis and more data collection should be performed to explore causal relationship between these factors and innovation. Future studies using path analysis should be completed to determine whether each of the correlated factors predicts innovation or not. Future case studies should explore innovation between the multidisciplinary and monodisciplinary groups while controlling for confounding factors like the nature of the project, supervisor and client.
8 Bibliography

(n.d.).


9 Appendices

9.1 Appendix A—Interview Questions

Interview Questions for the preliminary study in 2014-2015. Note that was a semi-structural interview and there was follow up questions and discussion based on the circumstance.

Interview Questions
1. Why did you take this course?
2. What expectations did you have of your team members? How did those expectations change throughout the year?
3. What expectations did you have of your client? How did those expectations change throughout the year?
4. What expectations did you have of your supervisor? How did those expectations change throughout the year?
5. What was the most significant aspect of your own disciplinary knowledge that you applied and/or taught to your teammates during the course of the project?
6. What was the most significant aspect of knowledge outside your discipline that you learned/were taught by your teammates/applied during the course of the project?
7. How has working in a multidisciplinary team informed your ideas about engineering practice and your future career goals?
8. What was your favorite part of the course?
9. How do you think your experience in the course might have been improved?
10. Compare your experience from this course to any other design work that you have completed in your home department.
11. What are your multidisciplinary team experiences so far?
12. What do you think you can do to make a multidisciplinary team effective?
13. What do you think you need to learn to become a more effective team member in a multidisciplinary environment?
14. What was the most important thing you learned about being an effective team-member in a multidisciplinary environment through this project?
9.2 Appendix B–Interview Questions

This section contains a questionnaire for the semi-structural interview for the second study for the 2015-2016 school year that was a follow up with students who participated in the video recordings. Both in Multidisciplinary and Mechanical capstone.

**Semi-structured Interview Questions**

1. With examples, explain how you describe your experience in your capstone project? What was successful and what didn’t work well?
2. If creativity is defined as ………; how creative were the ideas developed by you and your team members?
3. With examples, explain what might have facilitated or hindered developing creative ideas by you and your team.
4. With examples, explain whether or not you were able to implement your [new] ideas.
5. With examples, explain what might have facilitated or hindered implementing your ideas.
6. In your capstone project, have you had gone through design iteration? With examples, explain reasons for your answer (why or why not).
7. Usually, coming up with new ideas/solutions requires taking risk and jeopardizing failure; in your capstone project, did you feel safe taking the risk? With examples, explain reason for your answer (why or why not).
   - With example, explain how your client/supervisor/team members encourage you or discourage you of taking risk.
8. With examples, explain whether your unique skills have been appreciated by your team members. Why or why not?
9. With example what did you teach to other disciplines and what did you learn from them?
10. With examples, explain how comfortable were you asking help from your team members. Why or why not?
11. With examples, explain to which extent were you able to rely on other team members’ expertise to make the project work.
12. With examples, explain whether you and your team members shared the same standards for quality of work. Why or why not?
13. With examples, explain whether you and your team members shared the same vision of the project. Why or why not?
14. With examples, explain what might have facilitated or limited effective communication with your client/advisor/team members.
15. With examples, explain how working in multi-disciplinary team might have been different than working with a team from your home department.
16. With examples, explain what you appreciated / not appreciated working in a multi-disciplinary team.
17. With examples, explain how working in multi-disciplinary team might have facilitated or hindered developing creative ideas.
18. With examples, explain how do you describe your ideal capstone project.
19. With examples, explain what might be done to improve capstone projects (or to allow developing creative solutions).
20. Would you suggest this to a 3rd fellow from your department? Why?
21. Did you do PEY or not? If yes how did it affect your performance in this capstone?
22. Give me an example that another team member from another disciple pointed out something or brought an idea that you never taught of …
23. What do you think about the size of your team?
24. Do you think the project had a fair share of work for every discipline who was involved?
25. Do you think everyone was motivated for the project?

9.3 Appendix C–SPSS Outputs

This section contains the outputs from the SPSS software. This includes the reliability tests, Mann-Whitney U test and partial correlations.

**9.3.1 Reliability Test for each Construct**

The first set of results is associated with the multidisciplinary group and the second set is associated with the monodisciplinary students (Mechanical and Industrial).

**Table 11 Cronbach’s Alpha values**

<table>
<thead>
<tr>
<th>Cronbach’s alpha</th>
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<th>Cronbach’s alpha</th>
<th>Internal consistency</th>
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9.3.2 Reliability Test for Multidisciplinary Group

Table 12 Reliability test for psychological safety questions

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Table 13 Reliability test for innovation questions

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Table 14 Reliability test for collaborative learning questions

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Table 16 Reliability test for external communication questions

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Table 17 Reliability test for vision questions

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Table 18 Reliability test for internal support for innovation questions

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9.3.3 Reliability Test for Monodisciplinary Group

Table 19 Reliability test for psychological safety questions

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Table 24 Reliability test for vision questions

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9.3.4 Ranking of Mann-Whitney U test

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9.3.5 Appendix Partial Correlations

This section includes the partial correlations. The correlation between each pair of variables is being measured while controlling for the rest of the variables.

### Correlations

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### Correlations

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9.4 Appendix D–Ethic and Provostial Approval Letter

This letter is the provostial approval that was required starting 2015-16 school year.

November 20, 2015

Dear Professor Behdinan,

Re: A qualitative and quantitative analysis of the effect of multidisciplinary capstone design on teamwork and innovation

Please accept this letter as permission from the Office of the Vice President and Provost to access faculty and students at the University of Toronto for the purpose of your research project as outlined in your proposal dated September 18, 2015.

If, during the course of your research, any significant changes occur to the information provided in your proposal, particularly in regards to your access to faculty, you will be responsible for notifying our office.

Thank you for completing the Confidentiality Agreement. We remind you that maintaining the confidentiality of faculty and staff throughout your project is of utmost importance and take this as your assurance that individuals used in your research will not be presented in any way which will allow for their identification and that information provided will only be used in the manner outlined in your proposal.

We wish you luck in undertaking your research.

Yours sincerely,

Sioban Nelson,
Vice-Provost, Faculty & Academic Life

cc: Office of the Vice-Provost Students & First Entry Divisions

/sr
This letter is the ethic approval for the first study that was conducted in 2014-15 school year.

PROTOCOL REFERENCE # 31983

September 24, 2015

Dr. Kamran Behdianan  Ms. Narges Balouchestani Asli
DEPT OF MECHANICAL & INDUSTRIAL ENG  DEPT OF MECHANICAL & INDUSTRIAL ENG
FAC OF APPLIED SCI & ENG  FAC OF APPLIED SCI & ENG

Dear Dr. Behdianan and Ms. Narges Balouchestani Asli,

Re: Your research protocol entitled, "A qualitative and quantitate analysis of the effect of multidisciplinary capstone design on teamwork and innovation"

ETHICS APPROVAL  Original Approval Date: September 24, 2015
Expiry Date: September 23, 2016
Continuing Review Level: 1

We are writing to advise you that the Health Sciences Research Ethics Board (REB) has granted approval to the above-named research protocol under the REB’s delegated review process. Your protocol has been approved for a period of one year and ongoing research under this protocol must be renewed prior to the expiry date.

Any changes to the approved protocol or consent materials must be reviewed and approved through the amendment process prior to its implementation. Any adverse or unanticipated events in the research should be reported to the Office of Research Ethics as soon as possible.

Please ensure that you submit an Annual Renewal Form or a Study Completion Report 15 to 30 days prior to the expiry date of your current ethics approval. Note that annual renewals for studies cannot be accepted more than 30 days prior to the date of expiry.

If your research is funded by a third party, please contact the assigned Research Funding Officer in Research Services to ensure that your funds are released.

Best wishes for the successful completion of your research.

Yours sincerely,

[Signature]

Dr. [Signature]
This letter is the ethic approval for the first study that was conducted in 2014-16 school year.

PROTOCOL REFERENCE # 31379

February 25, 2015

Dr. Kamran Behdinan
DEPT OF MECHANICAL & INDUSTRIAL ENG
FAC OF APPLIED SCI & ENG

Ms. Narges Balouchestani Asli
DEPT OF MECHANICAL & INDUSTRIAL ENG
FAC OF APPLIED SCI & ENG

Dear Dr. Behdinan and Ms. Narges Balouchestani Asli,

Re: Your research protocol entitled, "Practicing engineering design: An exploration of the acquisition, transfer, communication and application of engineering knowledge in an undergraduate multidisciplinary capstone design course"

ETHICS APPROVAL

Original Approval Date: February 25, 2015
Expiry Date: February 24, 2016
Continuing Review Level: 1

We are writing to advise you that the Health Sciences Research Ethics Board (REB) has granted approval to the above-named research protocol under the REB's delegated review process. Your protocol has been approved for a period of one year and ongoing research under this protocol must be renewed prior to the expiry date.

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If your research is funded by a third party, please contact the assigned Research Funding Officer in Research Services to ensure that your funds are released.

Best wishes for the successful completion of your research.

Yours sincerely,

[Signature]

[Signature]
9.5 Appendix E–Informed Consent for Student Data

This section contains letter of consent that was given to students in study one and two.

INFORMED CONSENT FOR STUDENT DATA

MASc student, Narges Balouchestani Asli is conducting research funded by the Natural Sciences and Engineering Research Council (NSERC) under Professor Kamran Behdinan’s supervision to study factors affecting engineering student innovation and team effectiveness in multidisciplinary design teams. The study consists of the analysis of data from one online survey and interviews. The research study may be extended over several years to examine how multidisciplinary design courses affect student innovation over a longer period of time. Study results will be used to improve the APS490 course and will also be published in academic journals. We encourage you to take part in this study.

Your participation in this study is entirely voluntary, and your decision to participate (or not) will not affect your grades in this course. Neither Professor Behdinan nor anyone else involved with evaluating students will know whether or not you decide to participate. If you choose not to allow your data to be used for this study, you will not be penalized in any way.

If you do decide to participate, participation will not require more than 15 min of your time for the survey.

Your data will be treated with full confidentiality. Narges Balouchestani Asli will ensure that all identifying information is removed from the data before it is shared with anyone else involved in the project. Your data and information is not available to anyone involved with grading of the course. The result of this study will be available to course coordinator in an anonymized manner, so no one from the teaching team will have access to the information unless it is being anonymized by Narges Balouchestani Asli. If you agree to participate, but change your mind later, you can email Narges Balouchestani Asli and tell her that you would like to withdraw from the study. You are able to withdraw from this phase of the study up to and including April 10th, 2015, the first day of exams.

As compensation for allowing us to analyze your data, you will have the opportunity to enter your name into a draw to win a gift certificate worth $100.

If you would like to see a summary of the results of this study, you may add your e-mail to a mailing list to see a copy of the research report once it comes out (see below).

If you have any questions about this study, or to withdraw from the study at any time, contact Narges Balouchestani Asli at narges.balouchestaniasli@mail.utoronto.ca or 647-893-6844. For more information about your rights as a participant of a research study, you can contact the Office of Research Ethics at ethics.review@utoronto.ca or at 416-946-3273. Please click on one of the two options below to indicate your willingness to participate in this study.
I would like to receive a summary of the results when the study is complete. (Include email address below)

I would like to be entered to win the gift certificate. (Include email address below)

Email address: _________________________________________

I agree to have my data  I do not agree to have my data

Increase your participation and your learning about teamwork and communication!

In addition to your participation in the study listed above we are looking for 30 students who would be interested in being debriefed on their learning. Students will be accepted into this study group on a first-come first-served basis by emailing Narges Balouchestani Asli indicating that you would like to participate in the interview component of the study.

Students who participate in this additional component of the study will:

- Participate in a 30 min interview at the conclusion of their team experience

Your participation in this component of the study is entirely voluntary, and your decision to participate, or not, will not affect your grades in this course. Participation in this study will not affect your performance in this course in any manner. As compensation for allowing us to follow you through APS490, you will receive a gift certificate worth $20 in addition to your entry into the draw for the $100 gift certificate listed above. Your data will be treated with full confidentiality. Narges Balouchestani Asli will ensure that all identifying information is removed from the data before it is shared with anyone else involved in the project. If you agree to participate, but change your mind later on, you can email Narges Balouchestani Asli and tell her that you would like to withdraw from the study. Withdrawal from the study removes your participation in an interview about your teamwork and communication at the end of term only (by April 10th which is the last day of classes).

The interviews will be conducted in private conference room, in which all windows to the room will be covered to ensure none can see who is participating in the interviews. The interview schedule will be set up by email. Narges Balouchestani Asli will be contacting students by email. She will be booking private meeting rooms through the Engineering Communication Program, on campus, but that the exact locations will depend on availability when the interviews are scheduled.

If you have any questions about this study, or to withdraw after providing consent, you can contact Narges Balouchestani Asli at narges.balouchestaniasli@mail.utoronto.ca or 647-893-5844. For more information about your rights as a participant of a research study you can contact the Office of Research Ethics at ethics.review@utoronto.ca or at 416-946-3273.
INFORMED CONSENT FOR STUDENT DATA

MASc student, Narges Balouchestani Asli is conducting research funded by the Natural Sciences and Engineering Research Council (NSERC) under Professor Kamran Behdinan’s supervision to study factors affecting engineering student innovation and team effectiveness in capstone design courses (both Multidisciplinary and Monodisciplinary). The study consists of the analysis of data from two online surveys, interviews and video recorded groups. The research study may be extended over several years to examine how multidisciplinary design courses affect student innovation over a longer period of time. Study results will be used to improve capstone courses and will also be published in academic journals. We encourage you to take part in this study.

Your participation in this study is entirely voluntary, and your decision to participate (or not) will not affect your grades in this course. No one involved with evaluating students will know whether or not you decide to participate. If you choose not to allow your data to be used for this study, you will not be penalized in any way.

If you do decide to participate in the survey, participation will not require more than 30 minutes of your time.

As compensation for allowing us to analyze your data, you will have the opportunity to enter your name into a draw to win 1 of 6 $50 cash prizes ($300 in total).

If you decide to participate in the video recorded group, then you are asked to video record 3 of your meetings and there will be a follow up 30-40min interview. Each member of the group will be compensated $30 for their time.

Your data will be treated with full confidentiality. Narges Balouchestani Asli will ensure that all identifying information is removed from the data before it is shared with anyone else involved in the project. Your data and information is not available to anyone involved with grading of the course. The results of this study will be available to the course coordinator in an anonymized manner, so the teaching team will only be able access to the information collected from you once it has been anonymized. If you agree to participate, but change your mind later, you can email Narges Balouchestani Asli and inform her that you would like to withdraw from the study. You are able to withdraw from this phase of the study up to and including April 10th, 2016, which is the first day of exams.

If you would like to see a summary of the results of this study, you may add your e-mail to a mailing list to see a copy of the research report once it comes out (see below).

If you have any questions about this study, or to withdraw from the study at any time, contact Narges Balouchestani Asli at narges.balouchestaniasli@mail.utoronto.ca or 647-893-6844. For more information about your rights as a participant of a research study, you can contact the Office of Research Ethics at ethics.review@utoronto.ca or at 416-946-3273. Please click on one of the two options below to indicate your willingness to participate in this study.
I would like to receive a summary of the results of the study once it is complete. (Include email address below)

I would like to be entered to win a cash prize. (Include email address below)

Email address: _________________________________________

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I agree to have my data

I do not agree to have my data

In addition to your participation in the survey listed above we are looking for two teams in each course who would be interested in having three of their team meetings video recorded. Students will be accepted into this study group on a first-come, first-served basis by emailing Narges Balouchestani Asli and indicating that they would like to participate in the video-recorded component of the study.

**Students who participate in this additional component of the study will:**

- Complete the two surveys
- Have three team-meetings video-recorded
- Participate in a 30-40 min interview

During the interview, students will be asked to discuss their thinking and approach to dealing with specific incidents in their teamwork and communication during these three video-recorded team-meetings. They also will be asked about the creative process they used and whether their peers and supervisors supported for innovative capstone designs. Your participation in this component of the study is entirely voluntary, and your decision to participate, or not, will not affect your grades in this course. Participation in this study will not affect your performance in this course in any manner. As compensation for allowing us to record your meeting, you will receive $30 cash in addition to your entry into the draw for 1 of the 6 prize worth 50$ bash listed above. Your data will be treated with full confidentiality. Narges Balouchestani Asli will ensure that all identifying information is removed from the data before it is shared with anyone else involved in the project. If you agree to participate, but change your mind later on, you can email Narges Balouchestani Asli and tell her that you would like to withdraw from the study.

If you have any questions about this study, or wish to withdraw after providing consent, you can contact Narges Balouchestani Asli at narges.balouchestaniasli@mail.utoronto.ca or 647-893-5844. For more information about your rights as a participant of a research study you can contact the Office of Research Ethics at ethics.review@utoronto.ca or at 416-946-3273