

## **Exploring Innovation, Psychological Safety, Communication, and Knowledge Application in a Multidisciplinary Capstone Design Course**

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## **Abstract**

In recent years, engineering schools have been inspired by accreditation bodies to incorporate multidisciplinary teaming in their curricula, and hence engineering schools have started to offer multidisciplinary capstone design courses. These courses give senior engineering students industry/client based projects in order to prepare them for today's diverse educational and professional work place. In contrast to monodisciplinary capstones, multidisciplinary capstones create a diverse team of students from different engineering disciplines to design, build, and test proof of concepts for an industry based project. There is limited quantitative and qualitative research about multidisciplinary capstone's performance. Hence to provide insight on multidisciplinary capstone's performance, we explored the relationship between innovation (at the individual level and at the 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. We hypothesised that multidisciplinary teams are likely to produce innovative solutions due to their functional diversity. However, functional diversity can also lead to conflict. According to literature, multidisciplinary teams have low psychological safety score because of their diversity. Low psychological safety affects team's collaborative learning and efficiency. We investigated these factors and relationships in multidisciplinary capstone.

A mix of quantitative and qualitative methods were used in this study. 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.

Our research shows that multidisciplinary students are very innovative due to their knowledge diversity. However, there are certain barriers regarding the knowledge transfer, communication, and psychological safety that can be addressed during the development of such a course. Our research provides data-driven insights for development of an effective multidisciplinary capstone design 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.

## **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.<sup>25</sup>

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 design in their curricula.

There is a 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;<sup>1</sup> 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 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.

In this study, we hypothesized that multidisciplinary teams are likely to be innovative. However, these outcomes may be moderated by the psychological safety of the group and how much feedback they receive. We are also interested to explore how knowledge transfer is happening in these teams and how it correlates with other factors. This study examines these factors and outcomes in a multidisciplinary course at the University of Toronto. Quantitative and qualitative methods were used in this study.

We asked the students who were taking the multidisciplinary capstone a set of survey questions on innovation, psychological safety, knowledge use and transfer, and feedback. We examined the relationships between our measurements of each of these variables to understand the innovation in this new multidisciplinary capstone course, and explored the team dynamics that arise and affect it.

This study is the first part of a bigger research project that is currently (2015-2016 school year) investigating team level factors affecting innovation in a multidisciplinary capstone. The new proposed framework will be obtained by comparing monodisciplinary and multidisciplinary teams and their behaviors.

## **Introduction to the course framework**

Multidisciplinary capstone design course (APS490) is a multidisciplinary capstone engineering design course that was established by Professor Behdinan in 2013-2014 school year in the

Faculty of Applied Science and Engineering at the University of Toronto.<sup>2</sup> The goal is to create opportunities for students by providing a framework 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.<sup>1,2</sup> The range of projects that were offered to the students was very diverse with projects within aerospace, health, finance, defence, manufacturing, and education. Students had expertise in chemical engineering, electrical engineering, computer science, mechanical engineering, industrial engineering, materials science, and/or engineering science.<sup>3</sup> There are 6 departments and 3 institutions 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 the industry partner that is supporting the project and a supervisor from the academia. Clients mostly provide the requirement and the criteria for the projects. Supervisors mostly support the students in their design process and provide them with the insights and information. Both the clients and the supervisors grade and evaluate the students from different perspective.

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

### **Literature review and hypothesis**

Discussing errors, seeking feedback, and seeking information from teammates is associated with improved team performance and innovation.<sup>4,5</sup> Thus, we wished to ask students if they felt they had received enough feedback from their supervisors, clients, or each other. For teammates to give each other feedback, they must be comfortable, 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.<sup>4</sup>

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 are/or the technical details of the solutions.<sup>6,7</sup> 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,<sup>4</sup> we wished to explore the degree of psychological safety in the multidisciplinary capstone teams.

According to the literature, the high psychological safety concludes innovation.<sup>8</sup> Moreover, low psychological safety prohibits innovation behaviour.<sup>9</sup> In industry environment, psychological safety in a team enables contradictory perspectives and unique skills to be valued. This will then enables the team to draw individual knowledge and expertise to be more innovative.<sup>10</sup> We wish to investigate these factors and their correlation in educational environment with multidisciplinary capstone.

Functional diversity refers to the variation in education and professional experience between members of a team,<sup>11, 12</sup> as opposed to demographic, cultural, or ethnic diversity. Though students in APS490 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<sup>6</sup>. However, it has been found that the functional diversity of multidisciplinary teams leads to greater innovation.<sup>12, 13, 15</sup> This is believed to be the case because a more diverse group has more information and resources to draw from.

Moreover, more communications occur in multidisciplinary teams because team members must explain their own disciplines to each other.<sup>13</sup> That is why one of the objectives of this study was to examine knowledge transfer by measuring how much the students were applying and teaching their own discipline and how much they were 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.

The potential that multidisciplinary capstone teams may produce more innovative designs was one of the motivating factors in creating the APS490. Across studies of innovation, it 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.<sup>12, 5, 14</sup> Because of the demand for innovation, and the hope that it can be found in multidisciplinary teams, we asked capstone students a set of survey questions developed and validated by Scharf and colleagues (2014)<sup>24</sup> that collectively measures innovation. Students were asked to evaluate their own level of innovation, as well as that of their team as a whole.

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 each student is 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.<sup>16, 17, 26</sup> 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.<sup>18</sup>

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.<sup>15</sup> 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.<sup>4, 8, 19, 24</sup> 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.

We expect to find that the amount of feedback that students get from their teammates correlates with whether or not students are learning from each other and teaching each other, because they are likely to occur at the same time, during team meetings. We also 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.<sup>5</sup>

The effects of more or less feedback from clients and supervisors on psychological safety, knowledge transfer, and teammate feedback is difficult to predict, and may depend on the specific supervisor, client, student, and 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. Support for innovation from

organizational superiors is known to be a very important factor for innovation in industry.<sup>5, 16</sup> Therefore, we wished to examine whether clients and supervisors are actively encouraging students to find more innovative solutions.

## **Methods**

Both qualitative and quantitative methods were used for this study. Students in the 2014-2015 multidisciplinary capstone design course were asked to complete an electronic survey through an online platform. There was an optional interview as well in which 11 students participated. APS490 was comprised of 20 design teams from 6 engineering disciplines. Each team includes students from at least two disciplines.

The survey used Likert Scale responses to measure psychological safety, innovation, whether students were applying and teaching their knowledge, and whether students were learning from teammates (see Appendix A). Students also indicated if they received enough feedback from other students, clients, and supervisors using a 3-point Likert Scale. 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  $N = 46$ .

## **Psychological Safety**

We used a set of 9 questions for assessing psychological safety that were originally developed and validated by Edmonson and Mogelof.<sup>28, 4</sup> We modified the questions where applicable to better suit this study. Students report the level of psychological safety they felt in their group by selecting responses from a 5-point Likert Scale. The questions asked students how often their team either exhibited a psychologically safe environment or the opposite, by selecting responses in a range from “Almost Always” to “Almost Never”. Questions that were negative with respect to psychological safety were reverse coded.

## **Innovation**

Innovation was measured using a set of 11 questions that asked students to report the frequency of different behaviours that were necessary for innovation using a 5-point Likert Scale (“Almost Always” to “Almost Never”). This measure of innovation was constructed and validated by Scharf and colleagues.<sup>24</sup> Students were asked to make these estimates for both themselves, which we call individual innovation, and their team as a whole, which we call team innovation.

## **Apply, Learn, Teach**

Students were asked if they were applying knowledge from their own discipline, teaching it to others, or learning it from their teammates. Students used a 6-point Likert Scale (“Strongly Agree” to “Strongly Disagree”) to indicate how much they agreed with the statements: “I apply knowledge from my discipline.”; “I learn knowledge from other disciplines.” “I teach knowledge from my discipline.”

## **Feedback**

In the online survey, students were asked whether they received either too little, enough, or too much feedback from their client, their supervisor, and their teammates. The students had to click only one of those options to indicate their response.

## **Interviews**

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 choice. 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.

## **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 and colleagues,<sup>24</sup> 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.<sup>27</sup> 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, and applying knowledge, learning knowledge, and teaching knowledge from their discipline.

## **Results**

### **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.



## Correlations

**Table 1: Bivariate Correlations (Spearman's Rho)**

	<b>Psychological Safety</b>	<b>Team Innovation</b>	<b>Individual Innovation</b>	<b>Apply</b>	<b>Learn</b>	<b>Teach</b>	<b>Client Feedback</b>	<b>Supervisor Feedback</b>	<b>Teammate Feedback</b>
<b>Psychological Safety</b>	1								
<b>Team Innovation</b>	0.695**	1							
<b>Individual Innovation</b>	0.072	0.402**	1						
<b>Apply</b>	0.388**	0.199	0.267	1					
<b>Learn</b>	0.124	0.105	0.291*	0.139	1				
<b>Teach</b>	0.330*	0.275	0.438*	0.706**	0.079	1			
<b>Client Feedback</b>	0.071	0.12	-0.029	0.092	-0.132	0.038	1		
<b>Supervisor Feedback</b>	-0.029	0.257	0.029	-0.208	-0.001	-0.086	0.269	1	
<b>Teammate Feedback</b>	0.322*	0.325*	0.044	0.177	0.233	0.173	-0.028	-0.339*	1

\*p<0.05

\*\*p<0.01

Correlations between all measures are found in Table 1. 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 ( $p=0.07$ ).

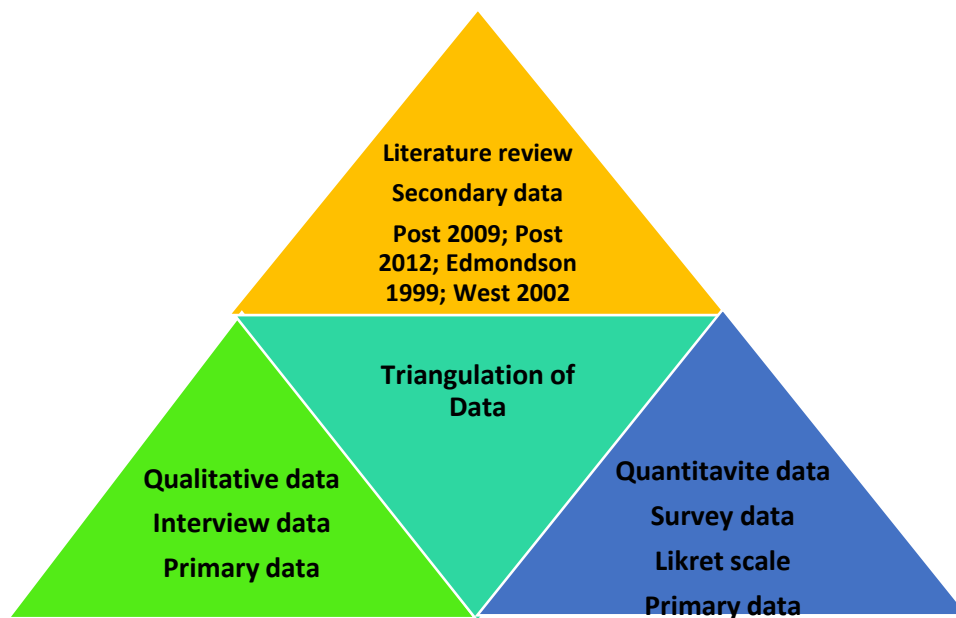
## Results of Interviews

The rationalistic and naturalistic approaches were used for data collection. Charmaz constructivist grounded theory was used to code and categorize the data and themes were developed by coding the data. We specifically coded for anything that was related to psychological safety and its effect on team innovation and performance. The following factors were the indicators of psychological safety: trust, comfort, ability to voice opinions, safe to take risk, safe to ask for help, not being rejected for being from a different discipline, unique skills are valued and utilized, free and open communication within the team and constructive feedback.

The trend for knowledge transfer and feedback was not investigated further here. For more detail regarding the relation between knowledge transfer and communication, you can refer to our earlier paper.<sup>3</sup> 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.

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 has a high correlation with innovation. The second source of data comes from the Likert scale responses within the quantitative part that also found a strong correlation between team innovation and psychological 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 and predicted team innovation and performance.

Triangulation of data shows that low psychological safety seems to decrease team innovation while a 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:

Sample quote:

*"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 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 appears to lead to the project success and allowed student's 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 another disciple, in this case an ECE student. These students also mentioned they learnt a lot form the ECE member during the integration process.

Sample quote:

*"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 commutation which appears to build trust in the team. 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. These factor 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 member 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.

Sample quote:

*“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.

## **Discussion**

From our survey of students in the 2014-2015 multidisciplinary capstone design course, we found correlations between each element of knowledge transfer and application, psychological safety, feedback from all parties, and innovation. Some correlations in this exploratory study were expected, and some were unexpected and warrant further study.

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.

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.<sup>8, 19</sup> 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.

The correlations between psychological safety and team feedback and between psychological safety and team innovation are consistent with the literature.<sup>8, 19, 5, 4</sup> 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.

The correlation between psychological safety and innovation was further confirmed by triangulation of data with the qualitative interviews and literature. Interviews provided support for our interpretation that psychological safety is important for team innovation. One student said of his group that "...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." Clearly, this student felt his team had little psychological safety, and that directly prevented them from working together to finish the project. His mention of motivation indicates that motivation was a contributing factor and an important factor for psychological safety. This agrees with the theory of the team climate for innovation proposed by Anderson and West.<sup>20</sup>

Another student reported that their team experienced excellent psychological safety, and that it facilitated good feedback. He said, "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 perspective." 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.

In this quote, the student also states that getting everyone's input, and being able to draw from the "different logical perspective" was one of the main objectives of the capstone course. 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. Other students also have reported that the functional diversity of their multidisciplinary capstone teams allowed them to implement their design ideas. For instance, one student indicated that a prototype of their design would not have been possible without the expertise of someone from another discipline. He said, "We were not able to get this design into prototyping stage without having a student from ECE. His knowledge and expertise gave the group the confidence to move forward and make our imagination into reality. If we were a group of mechanical students only we could design it but we were not able to build it." Another student 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." These qualitative findings suggest that multidisciplinary capstone students will be better at innovating and implementing designs than their monodisciplinary peers.

The finding that team innovation correlates strongly 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.

Individual innovation correlates very strongly 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. Individual innovation also 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.<sup>12</sup> 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.<sup>8</sup>

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.

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 the teamwork and the knowledge transfer that we found to be linked to improved team innovation.

It is worthwhile to mention that studies show that there are many other factors like motivation, critical thinking and entrepreneurial mind-set that results in innovation. But in this study, we focused on the effect of functional diversity.<sup>21</sup>

### **Study Limitations**

Our analysis in this study were limited by the sample size and dimensions. Although the sample was large enough to allow for a robust analysis, the sample did not include all students in the capstone course. This means the analysis that requires opinions of all members of teams were impossible to complete, and so 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. Moreover, we do not have an objective third party rating of innovativeness of students and their teams, and thus cannot be sure that ratings given by students are not biased.<sup>22</sup>

### **Future work**

To address the limitations of this study and take this research to the next level in 2015-2016 school year, we are conducting an extended version of our survey for both single disciplinary capstone students and multidisciplinary students to have a measure for comparison. We also included data from third parties like supervisors and clients to avoid any biases due to self-report nature of the data. We studied knowledge transfer in a border sense of collaborative learning. We also added a video recording to our qualitative analysis that would monitor two teams from single disciplinary in mechanical engineering and multidisciplinary throughout the year to have a closer look at their team dynamics. An extensive literature review was also conducted to find other factors that can possibly lead to innovation and those factors were incorporated to the survey questions and interviews.

### **Implications and strategies for multidisciplinary capstone design courses**

This study was performed for the multidisciplinary capstone design course here at the University of Toronto. Different educational institutions might have different platforms for their multidisciplinary capstone design courses or any work with multidisciplinary nature in engineering. But there are findings from this study that is generalizable and can shed new lights on how to run a better multidisciplinary course and a better environment where innovation can flourish from the advantage of functional diversity. The high correlation between psychological safety and innovation indicates that for students from different disciplines to be innovative, there should be a framework that help students to improve the elements that lead to higher psychological safety of the team. This can be done through a series of workshops to inform students and give them resources and strategies on how to tackle these possible problems. Moreover, a new feedback system can be put in place to help students identify problems, like lack of communication or trust, early on, and thereby to resolve them soon. An example of this platform is the Team Effectiveness Learning System (TELS).<sup>23</sup> TELS provides students with peer-assessment and self-assessment and feedback related to teamwork. This is essential to help improving psychological safety in the teams. Such a platform can give supervisors access to this information which helps them to guide students during the course of the project. The software also guides students towards lessons, exercises, and best practices to improve their behaviors in identified areas of growth. Having in place strategies to make sure that the projects for these type of courses have fair amount of work for each involved discipline, to keep a good dynamic of knowledge transfer, is an important factor too.

Furthermore, this research informs educational institutions on how their feedback and input as a superiors and faculty advisors plays a role in innovation. The feedback either provide support for innovation, or limits students and imposes constraints. This study was an exploratory research that led to our extensive research project this year. Since there is limited quantitative and qualitative research on multidisciplinary capstone course, this exploratory research can be a guide for finding further areas to explore and to have different strategies in place for course

improvement. Identifying the challenges that students face in multidisciplinary environment will lead to the discussion on how to tackle these challenges.

The results for this study help course coordinators to plan accordingly for student 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.

Having in place a system for peer evaluation and self-evaluation to give feedback to students and supervisors will prevent low psychological safety of the team that inhibits innovative behaviors. There are tremendous opportunities for innovative solutions when it comes to multidisciplinary team so long as one can overcome barriers like psychological safety of the team by providing support to students.

## **Conclusions**

This study explored the relationships between innovation at the individual level and at the team level, psychological safety, knowledge transfer, application of one's knowledge, and feedback from teammates, supervisors, and clients in a multidisciplinary engineering capstone course at the University of Toronto. We found correlations that support the idea that feedback, knowledge transfer, psychological safety, and the multidisciplinary nature of capstone are positively related to innovation at the team level and/or at the individual level. However, we also found unexpected correlations between applying one's own education and psychological safety, team innovation and individual innovation. It was also surprising to find that learning knowledge from another discipline from one's teammates was not correlated with psychological safety, but teaching knowledge from one's own discipline to teammates was correlated with psychological safety. Each of these findings should be further examined, as well as the tools used to measure them.

The study of innovation occurs in both academia and industry, in many cultures, and examines a great number of variables that have some effect in one context, but not others. Although there are common factors that may or may not influence innovation, how much these factors affect innovation depends significantly on the context of the organization and the project they are investigated in.<sup>16</sup> But it is plausible that the results of our study are generalizable to all engineering capstone courses. Because multidisciplinary capstone seeks to mimic the working conditions of engineers, we are likely to see more multidisciplinary capstone courses in educational institutions across the world. Further understanding of how multidisciplinary problems and teams affect the innovation in the students' output, as well as their experiences in learning from each other and in resolving conflicts will allow the design of these courses to be improved.

The evidence from this study shows that due to functional diversity of multidisciplinary teams and the extensive knowledge transfer and communication that happens within the teams, these multidisciplinary teams can potentially be more innovative than monodisciplinary courses because of factors like better psychological safety of the team.



The knowledge transfer that happens in multidisciplinary teams due to their functional diversity appears to have a positive effect on creativity part of innovation. In many cases, students reported that they were able to see the problem from different perspectives, and hence new ideas flourished during these knowledge transfers which they did not experience in their home department's courses. The functional diversity of the team members also enables the implementation part of the innovation. Students reported that they would have not got to the prototyping stage if it was not because of the multidisciplinary nature of their team.

Future studies using path analysis should be completed to determine whether psychological safety predicts innovation and feedback, and whether more feedback predicts greater innovation. This study only explored correlations and further studies should take place to find causation.

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