A Qualitative Study of Team Level Factors Affecting Innovation

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Abstract –*Innovation is a necessity to embrace possibilities and face challenges and problems in our continuously changing world. Multidisciplinary capstones can be a place for students to be innovative. Students not only get a chance to work on a real project from industry, but they also work with students from different disciplines. This diversity of knowledge and perspectives can lead to team innovation. This paper explores team level factors affecting innovation in 4th year multidisciplinary capstone design at the University of Toronto. This paper is a qualitative study that explores the effect of diversity of knowledge, support for innovation from supervisor and client, team size, and team vision on innovation. Our research sheds some light on what behaviors in teams lead to innovation. Supporting and encouraging these behaviors from educational institutions provides an environment for students to be more innovative.*

Keywords: Innovation, Multidisciplinary Education, Capstone Design, Qualitative Research, Industry Based Projects

1. INTRODUCTION

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 [1]. 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 [2]. 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 [3]. This study is conducted on a newly introduced multidisciplinary capstone project at the University of Toronto [4]. 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 [5] 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 realities. 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' [6]. Main characteristics of innovation-supportive environments are encouraging risk-taking and tolerating failure [7]. These two interrelated elements are essential to encourage the expression of novel ideas and putting these ideas to work. Tied to these elements, is the space allowed for ideas to originate at the grass root level, rather than dictating them from above, as well as the acknowledgment and rewarding of these ideas [8]. 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 Hülsheger, 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 is 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 effect innovation in a multidisciplinary, engineering capstone project. The results of this study would provide spaces to better support innovation in engineering education, a demand that we urgently need today more than ever.

2. CONTEXT AND METHODOLOGY

This study is a part of a larger one that aims at examining innovation and factors that affect it in different engineering capstone projects at the University of Toronto. Innovation is compared between monodisciplinary teams (e.g. from mechanical engineering) and multidisciplinary teams. All teams are at year four of their programs.

In this paper, we focus on the preliminary results that emerged from qualitative analysis of data obtained from one multidisciplinary team. We particularly examine factors that affect innovation in a multidisciplinary team. This team is composed of six members: one member from mechanical engineering; one from industrial engineering; one from electrical engineering; two members from the engineering science program with a focus on electrical and computer engineering; and one with a computer science background, from the faculty of Arts and Science. In the multidisciplinary capstone, students are given a project from industry. The team is assigned to a supervisor and an industry client. They have 8 months to complete the project from idea generation to implementation. The final product is evaluated by both the course supervisor and the client.

The main task, for this team, was to develop an effective and efficient training method for aviation mechanics that incorporates contextual switching. Their final product was a wearable training platform that delivered a landing gear assembly course that overlays instructions on a trainee's field of view. Their prototype demonstrates the capabilities and limitations of the current generation of wearables for training purposes.

As mentioned earlier, 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 [9]. 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. 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 [10]. 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 [11]: 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 next section.

3. RESULT AND DISCUSSION

Students' perception of their innovation was positive. They believed that they came up with a novel way of solving the problem at hand. The results of interviews along with the video recordings show that these five factors hindered or facilitated innovation: the effect of 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.

3.1 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 [12,13]. 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 [14]. Another quantitative study shows that multidisciplinary students were rated higher than mono-disciplinary students by external assessor about their innovation [15].

When analysing the data, we found that coming from different disciplines allowed team members to confidently express their ideas and successfully implement them. 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 [16]. 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. 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 [17]:

"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 are team vision and task orientation.

3.2 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 [7]. 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 seem 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, so 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."

3.3 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 [18]. Supervisors and directors are encouraged to be explicit about expecting novel ideas, from team members, and to provide practical support to these novel ideas [19]. In addition, and as mentioned earlier, rewarding creativity and provide spaces for risk taking tend to highly support innovation [6] and [5].

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 to the practical by narrowing their ideas and applying them. 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 [20]. 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 future work and 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 [21]. Hence, the supervisor influenced the team positively in both stages of innovation which are creativity and implementation.

3.4 The effect of the client (industry partner)

The client played contradictory roles in supporting innovation. On one hand, he provided spaces for novel ideas to develop 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 seems also to be a crucial factor for innovation. External resources not only affect implementation, but can also interrupt the design process and the flow of novel ideas, which would negatively affect innovation.

3.5 Team size

Capstone projects with a multidisciplinary nature usually have a broader scope than monodisciplinary ones; this 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 (translated into larger team size) and 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.

7. CONCLUSION

Multidisciplinary teams' can be very innovative due to their functional diversity. Factors like trust, a shared vision and similar expectations across the team enabled creative ideas to flourish from this diversity. 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 conflict from happening within this team.

Although having a team of students with diverse skillsets enables creative ideas to come forward, it is important to create a culture of innovation that would support and reward student's innovation. Also, providing resources played a great role during the implementation side of this project that affected innovation. In this study, it wasn't clear whether the client facilitated or hindered risk taking; that is a factor to be explored further.

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