A COLLABORATIVE LEARNING AND TRANSDISCIPLINARY MODEL FOR UNDERGRADUATE INNOVATION EDUCATION

by

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Dedicated to my parents

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ABSTRACT

A student's education should be reflective of the innovative and progressive nature of the professional world. While innovation was previously viewed as an economic driver or technological concept in the 20th century, modern times have innovation permeating into all branches of society, intending to seek and develop new knowledge and ideas across any academic and professional disciplines. With this inclusion of innovation in all aspects of society, students should be provided educational opportunities to develop innovation capabilities, skills, and mindsets that can better prepare them for the professional world as well as for making both societal and personal impact. Innovation-focused education has been positioned to aid in 1) developing social responsibility in students, 2) fostering innovative behaviors that can benefit the organizations in which students become part of in their future, 3) empowering students to pursue their own personal ventures, and 4) enhancing the economy of a nation. And, using a transdisciplinary approach to teaching innovation, can be one approach to bridge, or even break down, the silos that exist within modern higher education—creating a more authentic community of practice to nourish student learning and their innovative ideas. Researchers have found that innovation capabilities are not typically a by-product of traditional comprehensive education and without specific curriculum to cultivate innovation practices among students across majors, many may be missing out on valuable knowledge and skillsets. Addressing this concern, an undergraduate model at Purdue University has been developed to provide students with the time, resources, and opportunities to enhance their innovation capabilities through co-teaching and co-learning from faculty and students from differing academic units/colleges. This model brings together the disciplinary lenses from three different colleges, including engineering technology, business management, and liberal arts. Engaging students in a transdisciplinary, authentic learning

experience across these academic units can allow them to form a community of practice by working on innovation projects over multiple semesters within an engaged network of faculty, peers, and mentors from a variety of disciplines. However, as this model is implemented there is a need to better understand how this collaborative approach to teaching innovation influences undergraduate learning. Therefore, this study 1) examined student perceptions of this innovation education model related to its co-teaching and co-learning pedagogical approach as well as 2) analyzed the influence of this model on student innovation skills (i.e., *integrative learning*, *teamwork*, and *problem solving*). To do so, data was collected from Likert-style prompts and open-ended survey responses and semi-structured interviews and analyzed using thematic coding and a non-parametric Wilcoxon signed-rank test. The results of this analysis revealed 1) working in teams is a necessary evil for many students, 2) cross-college collaboration enhances brainstorming and ideation in general, 3) a collaborative, transdisciplinary setting for learning allows for the application of prior knowledge, and 4) multiple instructors allowed for a greater range of feedback throughout the design process, among other findings in regard to student perceptions of the collaborative teaching and learning model. In addition, the results indicated that there was a statistically significant difference in the students' perceptions of their innovation capabilities related to all sub-constructs of both *integrative learning* and *problem solving*, while students' perceptions of their abilities relating to *teamwork* were less consistent. Leveraging these results, discussions around best ways to implement a similar model of teaching in other contexts, the benefits students identified from working collaboratively with individuals outside of their academic unit, and optimal strategies for developing this model have been brought to life. Also, aligning to the data collected in this study, recommendations for educational practice, such as consistency between instructors, alternative strategies for using a similar model in a different time-span, and students identified issues and potential solutions have been provided as well as continued needs for future research. All of this information is positioned to help inform future innovation education research, identifying benefits and drawbacks of the collaborative form of teaching and learning, and analyzing students' self-perceptions of the skills they developed. Hopefully, this information will be valuable as more institutions look toward transforming teaching and learning practices to provide more engaging, cross-college models that enhance the value of the learning experiences they provide to students on their campuses.

CHAPTER 1. INTRODUCTION

1.1 Context

With a world constantly moving forward, always looking for the next big breakthrough or solution to a variety of social problems, it is important for the education of students to reflect this continual technological development and societal advancement. Innovation-focused education is one method of preparing students for both personal and professional success in this ever-changing world. While innovation previously was viewed as an economic driver and/or technological concept in the 20th century, modern times have innovation permeating into all branches of society, intending to seek and develop new knowledge and ideas (Lindfors & Hilmola, 2016; Gunnarsdóttir, 2013). With this inclusion of innovation in society, students should then be provided the opportunities that can better prepare them for the professional world as well as for making both societal and personal impact. Novel approaches to innovation education have been attempted in the past (Bartholomew, Strimel, Swift, & Yoshikawa, 2018; Strimel, Kim, & Bosman, 2019; Johnston, Burleigh, & Wilson, 2011). Outcomes of these approaches range from developing social responsibility within students, to supplying students with the necessary skills to bring innovative behavior to future organizations, personal ventures, and the general economy (Thorsteinsson, 2014; Maritz et al., 2014). However, innovation knowledge and capabilities are not always an outcome of traditional comprehensive education today. And, without a specific learning experience that transcends academic disciplines to provide innovation skills such as critical thinking, creativity, and problem solving, students are missing out on valuable knowledge and practices (Lindfors & Hilmola, 2016, Gunnarsdóttir, 2013). Although innovation education can span the entirety of a student's educational career; without intentional incorporation of these skills across academic boundaries and disciplines, students can remain underprepared for the future of both work and learning (Roper, 2021). Accordingly, this study seeks to investigate a novel collaborative model of teaching and learning for undergraduate innovation education. This model was developed to provide students with the time, resources, and opportunities to enhance their innovation capabilities through co-teaching and co-learning from faculty and students from differing academic units/colleges. Specifically, this model brings together the disciplinary lenses from three different colleges, including engineering technology, business management, and liberal arts, to create a transdisciplinary and authentic learning experience that is situated, over multiple semesters, within student-driven innovation projects (Briller, Kelley, & Wirtz; Kelley, 2016; Kim & Strimel, 2019).

1.2 The Problem

Innovation education is a developing field that requires an in-depth understanding in order to effectively develop innovation capabilities and mindsets in students. The gap between the ever-evolving world and current undergraduate learning is continually expanding, with current undergraduate education remaining siloed in separate focus areas or disciplines, limiting students' opportunities to learn and develop innovation practices that cross disciplinary boundaries (Birx, 2019; Otto et al. 2022; Otto & Strimel, 2021; Roper, 2021). Many strategies for incorporating innovation-focused learning for undergraduate students have been attempted through design-based coursework or entrepreneurship programs, but there remains a need for novel approaches that will develop undergraduates' innovation habits through transdisciplinary learning environments and authentic experiences (Bartholomew, Strimel, Swift, & Yoshikawa, 2018; Kim & Strimel, 2019; Strimel, Kim, & Bosman, 2019; Rivers et al., 2015; Johnston, Burleigh, & Wilson, 2011; Haldane, 2018). Unfortunately, most of higher education remains siloed within individual departments and colleges, limiting transdisciplinary environments that are authentic to innovation ventures (Birx, 2019; Lindfors & Hilmola, 2016). However, one strategy that is being employed to help transform undergraduate learning in the pursuit of innovation is a cross-college collaborative teaching and learning model. This model for teaching undergraduate innovation includes co-teaching and co-learning with faculty and students across academic units/colleges, over multiple semesters, to a) foster a community to nourish the innovative ideas of students and b) develop cross-disciplinary innovation practices. The model specifically brings together the colleges of liberal arts, business management, and engineering technology to blend the disciplines in an attempt to promote shared practices of innovation that are more authentic as well as provide broader access to these practices to students regardless of the students' backgrounds. However, the specific problem addressed in this study is the need for better understanding how transdisciplinary strategies such as this collaborative model of teaching innovation influences undergraduate learning and the development of student innovation skills related to *integrative learning*, *teamwork*, and *problem solving*. As the world is ambiguous and uncertain in the way it develops, novel approaches that help foster undergraduate students' innovation knowledge, practices, and habits are needed; specifically, novel and authentic educational experiences should be established to better provide students both the time and opportunity to practice innovation within the contexts of their own passions while being embedded in a diverse community to learn from (Haldane, 2018; Roper, 2021).

1.3 Study Purpose

Collaborative learning (CL) is a strategy for teaching where students are grouped or paired for the purpose of achieving a common goal (Laal & Ghodsi, 2011). CL approach has been shown to benefit students socially, psychologically, and academically (Laal & Ghodsi, 2011; Roper, 2021), and as such, incorporating this strategy with innovation education may help provide students with richer learning experiences that span across academic disciplines and promote shared practices and mindsets for innovation. Innovation thinking, as an outcome of innovation education, has been a focus of the 21st century and is identified to involve creative thinking, critical thinking, reflective thinking, and decision making (Nakano & Wechsler, 2018; Cobo, 2013). Similarly, CL is believed to develop critical thinking and problem solving skills (Laal & Ghodsi, 2011; Roper, 2021), thus, by incorporating CL into a classroom setting, along with the benefits of transdisciplinary learning identified by Bartholomew, Strimel, Swift, and Yoshikawa (2018) and Johnston, Burleigh, and Wilson (2011), students can have the opportunity to develop innovation capabilities and ways of thinking. The combination of these strategies takes form in a novel, undergraduate transdisciplinary model where methods of co-teaching and co-learning across engineering technology, business management, and liberal arts academic units are employed to provide said opportunities to students. The purpose of this study is to then identify the influence that this model of teaching has on student learning by analyzing

1.4 Research Questions

The research questions that guided this study were:

RQ1: What are the perceptions of a collaborative teaching and learning model for innovation-focused undergraduate learning, including cross-college co-teaching and co-learning, for enhancing student learning?

RQ2: What is the perceived influence of a collaborative teaching and learning model for innovation-focused undergraduate learning, including cross-college co-teaching and co-learning, on student abilities in *integrative learning*, *teamwork*, and *problem solving*?

Research Question 1 was addressed using semi-structured student and alumni interviews as well as student responses to open-ended survey questions as the primary data sources. Research

Question 2 was addressed using student responses to Likert-scale survey items as the primary data source. Details relating to data collection, analysis, and findings will be discussed in Chapter 3.

1.5 Definitions

- **Collaborative Learning:** "The grouping and pairing of learners for the purpose of achieving a learning goal... an instruction method in which learners at various performance levels work together in small groups toward a common goal." (Laal & Ghodsi, 2011, p. 486)
- **Technological Literacy:** The ability and understanding for someone to effectively assess, acquire, and communicate information in a digital environment (Dakers & de Vries, 2006)
- **Nature of Technology:** The influences of technology in all aspects of life, including relating to mankind, the relationship between technology and science, the social role of technology, and any skills related (Digironimo, 2011; Xu et al. 2021).
- **Transdisciplinary:** "Transdisciplinary thinking forces one to think across, beyond, and through the academic disciplines to encompass all types of knowledge about an idea, issue, or subject." (Ertas, Maxwell, Rainey, & Tanik, 2003, p. 289)
- **Cross-College Collaboration:** The intentional practice of bringing students/faculty from various academic units/colleges together to teach and learn from each other, with the intention of knowledge transfer occurring between individuals who may not have the opportunity to meet.
- **Knowledge Transfer:** The involvement of two parties, one that has a need for knowledge while the other possesses said knowledge, where both are dependent and

share expectations of learning performance and satisfaction (Nemanich, Banks, & Vera, 2009)

- **Integrative Learning:** There are many definitions that could be applied to *integrative learning*; however, *integrative learning* for the purpose of this study is the intentional blending of various skills and knowledge developed from different disciplinary areas (Miller, 2005).
- **Teamwork:** "Behaviors under the control of individual team members (effort they put into team tasks, their manner of interacting with others on team, and the quantity and quality of contributions)," (AAC&U, 2009, p. 1).
- **Problem Solving:** "The process of designing, evaluating, and implementing a strategy to answer an open-ended question or achieve a desired goal," (AAC&U, 2009, p. 1).
- **Innovation Mindset:** "The internalization of innovation by individual members of the organization where innovation is instilled and ingrained along with the creation of a supportive organizational culture," (Kahn, 2018 p. 453)
- **Innovation Education:** Innovation education encompasses any pedagogical program or curriculum for training innovation knowledge and capabilities, often extending beyond the technical into personal and organizational qualities. (Maritz et. al., 2014)
- **Authentic Learning Experiences:** A pedagogical approach to learning where the learning is situated in the context of future use (Herrington, Reeves, & Oliver, 2013).
- **Co-Teaching:** An approach to teaching where instructors from differing academic departments work to teach a course in conjunction with one another, with the intention of expanding both student and instructor knowledge.

- **Co-Learning:** An approach to learning where students work in diverse groups in order to both apply and share their existing knowledge, as well as learn from their peers throughout the process.

1.6 Assumptions

Several assumptions were held throughout this study. First, it was assumed that participants could fully comprehend the prompts posed in the surveys and that they were able to respond to each prompt appropriately. It was also assumed that participants answered the survey as well as the interview questions authentically and truthfully, although some biases are acknowledged. Along with being honest, students participating in the co-learning of this model of teaching were assumed to have adequate knowledge within their chosen field. Having this knowledge would have allowed them to be active members of their class groups and be able to both provide their knowledge to, and receive information from, their peers throughout the CL experience. Similarly, it was assumed that the instructors were knowledgeable in their content areas, enough such that students and co-instructors alike would benefit from the knowledge possessed.

1.7 Limitations

There were limitations to this study. First the diversity of the study participants, regarding demographics, educational background, and existing knowledge, was random based on the student enrollment in the innovation education model under investigation. While some student majors were more represented in the model than others, this difference in diversity means the transfer of knowledge that occurs due to the co-learning model, which is a desired outcome of the educational model, may fluctuate between iterations of the courses depending on those enrolled at that time.

Furthermore, the data collected for this study is a part of a larger study funded by the National Science Foundation. Due to the researcher's involvement in this research, this study may be subject to issues with bias related to the interpretation of the data. Additional concerns for potential bias are prevalent due to the researcher being a former teaching assistant for one of the courses within the model. However, steps to ensure creditability and trustworthiness were taken which are discussed in Chapter 3.

The survey instrument used for this study was based upon the Association of American Colleges and Universities (AAC&U) Valid Assessment of Learning in Undergraduate Education (VALUE) rubrics. Along with the rubrics' validity, since its creation in 2009, they have been utilized by more than 5,895 unique institutions, including over 2,188 colleges and universities, allowing them to reach more than 70,000 individuals as of 2015 (AAC&U, 2009). While these rubrics themselves are validated and used in various studies, a limitation for this study is that the rubrics were used as a survey instrument. The validity of these rubrics is discussed further in Chapter 3. However, pertaining to these surveys, a limitation relating to the participant response rate and the fact that, due to the voluntary nature of the survey element, the response rate is less than 100 percent. Students were asked and reminded during each semester to fill out the surveys, but there was no direct benefit given for completion of the surveys to the students. Concerning methods of data collection, semi-structured interviews were also conducted following the students' educational experience. Interviews were limited to less than 60 minutes; however, due to their semi-structured nature, this timing is an estimate. Having an estimated time may have led to the limitation of not having the opportunity to hear all the student has to say. Probing questions were given to learn more about the students' experiences, with considerations about how to pose these questions while avoiding bias or leading questions. The development of the interview questions allowed time for additional probing questions, but the potential for missing some information remained.

1.8 Delimitations

Delimitations for this study begin by acknowledging that this study was not attempting to identify a method of measuring actual innovation capabilities in students. The study intended to identify the influence of a specific model of teaching innovation to undergraduate students through the measurement of students' self-efficacy in specific constructs relating to innovation. Measuring innovation is an ambiguous process and is not an intended outcome of this study. Another delimitation was that participating students for this study were sourced from the two unique co-taught courses of the novel innovation education model. These students typically are further along in the progression of their studies and may have more detailed and content-specific knowledge that could benefit their peers through the co-learning model. This excluded students in the introductory course of the model, primarily first-year students, from the study. Excluding these students allows for a greater focus on the scope of the problem, as well as lessens the pool of participants. The excluded students include many individuals who would not continue along with the innovation-education model, as the introductory coursework is also required for first-year students outside of the model itself.

1.9 Summary

This chapter discussed the context of the problem that was investigated, the purpose of this study, and the research questions that guided the study. Assumptions, limitations, and delimitations for the study were also identified, along with any useful definitions. In the following chapter, a literature review will provide an analysis of existing methods of innovation education, details on the benefits and drawbacks of both collaborative and transdisciplinary learning, and the implications of authentic learning environments and their place within education.

CHAPTER 2. REVIEW OF LITERATURE

2.1 Introduction

The developing need for teaching innovation capabilities and innovative ways of thinking encompasses both education, particularly higher education and professional realms of our society. Therefore, this research focuses on understanding undergraduate student self-efficacy in regard to learning innovation skills, while simultaneously analyzing the students' perceptions of a unique collaborative model of teaching and learning innovation practices at the undergraduate level. To frame this study within the current literature, this chapter will: 1) explore the need for intentional innovation education strategies, 2) identify benefits of some existing learning strategies, 3) seek to understand what motivates students to learn, and 4) analyze pedagogical strategies employed previously along with their influence on student learning. Additionally, this chapter will discuss a theoretical framework related to student motivation and its implications for student learning and innovation within an educational setting.

2.2 Literature Documenting the Problem

Innovation-focused learning has been a developing field for many years, but only recently has there been a push to develop this learning further in order to better prepare students for the professional world. Bartholomew, Strimel, Swift, & Yoshikawa (2018) identified many various strategies for incorporating transdisciplinary learning for undergraduate students that have been attempted within design-based coursework; however, there remains a need for novel approaches that will develop undergraduates' innovation habits through active learning environments and real-world experiences (Haldane, 2018). The National Academy of Engineering (2015) states, "innovative thinking should be an expectation of the university community and all students should be exposed to it early" (p.6). While this expectation is acknowledged by many, institutions continue to silo their subjects into individual departments or schools (Birx, 2019; Cobo, 2013), creating a disconnect in students' learning and the student's ability to apply it through various contexts. And, without a broader connection across these academic silos, too many students may lack opportunities to put their knowledge into practice through working with blended teams, acknowledging human elements in problem-solving, and transform innovative ideas into reliable investments of resources and time over the course of multiple semesters (Davidson, 2017). There are "islands of innovation" and "enthusiasts within the organization" that can push and support innovation learning, but they often "fail to generate overall, comprehensive innovation" (Avidov-Ungar & Eshet-Alkalai, 2011, p. 363). It is apparent within higher education there is a lack of intentional effort toward developing transformative teaching practices that may be necessary to promote more authentic, transdisciplinary, and meaningful learning experiences in the context of innovation.

Students entering higher education are seemingly underprepared during their general education and have been found to lack the necessary innovation skills when beginning their degree work (Lindfors & Hilmola, 2016). Innovation knowledge and practices are not currently an outcome of traditional comprehensive education, and without specific curriculum to provide innovation capabilities such as critical thinking, creativity, and problem solving, students are missing valuable learning (Lindfors & Hilmola, 2016). A student's traditional education is described by Keirl (2006) as, "both that education which is compulsory to all students of a certain age and that which is general in nature (e.g., literacy, numeracy, citizenship, technological literacy, ethics)," (p. 96), which encompasses most core coursework. While traditional pre-higher education technology courses center around skills education, (i.e., teaching technical skills such as using tools, drafting, etc.) this only makes up a portion of the knowledge students should learn through these courses (Keirl, 2006). Expanding upon the existing skills education and incorporating the cultural application of these skills, as well as the ability to understand and critique modern technologies, are left behind as students enter higher education. Providing opportunities for students to develop the skills of critical thinking, creativity, and problem-solving should then support the students' innovation capabilities as they progress through their educational pathways.

2.3 Literature Documenting the Purpose

While many strategies for innovation-focused education have been attempted, these attempts often remain siloed in various academic units based on traditional academic structures (Bartholomew, Strimel, Swift, Yoshikawa, 2018; Bosman, Kim, & Strimel, 2019; Kim & Strimel, 2019; Otto & Strimel, 2021; Cobo, 2013). However, CL is an approach to teaching that has been shown to blend academic disciplines to develop social skills in students (Sultan, Hussain, & Kanwal, 2020). However, there remains a gap concerning the best strategy for employing CL to teach innovation knowledge and practices in a transdisciplinary manner.

CL is defined as, "a philosophy of interaction and personal lifestyle where individuals are responsible for their actions, including learning and respect the abilities and contributions of their peers," and has been found to provide numerous benefits when learning (Laal & Ghodsi, 2011, p. 486). Specifically, CL has been found to develop social support for learners, build diversity in understanding concepts, develop learning communities, increase student self-esteem, reduce student learning anxiety, and promote critical thinking skills, among other benefits (Laal & Ghodsi, 2011; Johnsons, 1989; Pantiz, 1999). CL is often a key component found within transdisciplinary learning. Transdisciplinary learning, as a method of engaging students with peers outside of their discipline, creates collaborations between education and society while emphasizing knowledge integration and joint problem definition for students (Biberhofer & Rammel, 2017).

For the purposes of this study, CL and transdisciplinary learning take the form of a co-learning and co-teaching model of education that is situated within a more authentic learning environment with students across all majors and faculty working together from engineering technology, business management, and liberal arts. Co-learning is an approach that allows students to work together in diverse groups and gives both high and low ability learners across various subjects the opportunity to learn from each other (Sultan, Hussain, & Kanwal, 2020). On the other hand, co-teaching is a collaborative model of teaching wherein two or more instructors work together to teach the same course. A strong correlation has been found between the perceptions of collaborative teaching and the motivation for student achievement (Anwar, Asari, Husniah, & Asmara, 2021), providing insight into the potential effectiveness of this method of teaching.

2.4 Transdisciplinary Learning

Transdisciplinary learning emphasizes thinking beyond and through multiple academic disciplines to develop a more holistic view of concepts or issues (Ertas et. al., 2003). While these transdisciplinary teaching practices are emphasized within undergraduate education today, too often these practices are discussed synonymously with interdisciplinary and multi-disciplinary learning. However, each of these educational approaches hold different meanings (Park & Son, 2010). According to Rosenfield (1992) multidisciplinary learning focuses on the independence of various disciplines and working through them to assess common problems. The key difference between transdisciplinary learning and multidisciplinary learning is that a) transdisciplinary learning incorporates multiple disciplines of thinking during the learning process whereas the topics of learning transcend the individual disciplines and b) multidisciplinary learning connects the disciplines but preserves the silos in which they exist. Furthermore, interdisciplinary learning promotes communication between disciplines through joint work, while the content of work remains discipline specific (Rosenfield, 1992). Transdisciplinary learning is produced from the outcome of interdisciplinary work, pushing individuals to go beyond simply working and communicating with those from other disciplines to the point that the acquisition of knowledge and skills occurs between individuals (Park & Son, 2010). Transdisciplinary learning requires students to be competent in their own discipline and be capable of understanding and communicating with those in other disciplines (Park & Son, 2010). Supplying students with curriculum that promotes transdisciplinary learning in an authentic environment can provide them holistic knowledge outside of their discipline, diversifying their perspectives on future problems.

In this study, the CL model for innovation education under investigation has a goal to move toward providing a more transdisciplinary learning experience by leveraging the context of innovation. This model seeks to achieve this goal by having students work consistently together with individuals from other disciplines across multiple semesters. Having students work closely with each other, while instructors from various colleges/disciplines provide feedback and guiding thoughts, is positioned to encourage students to discuss critically with their peers the opportunities for developing innovative solutions to valid problems. Students are given the opportunity to express their opinions and knowledge to supply information that the other group members may not have considered due to their backgrounds. The transdisciplinary nature of the model extends to the instructors as well. Instructors from varying disciplines work to develop, organize, and teach the courses simultaneously with one another. This approach can potentially provide both students and instructors with a broader background of knowledge and more diverse viewpoints than any single instructor may have. However, it is now important to better understand how this model for undergraduate innovation education can influence student innovation capabilities as well as the motivation for learning which can be critical now as many question the value of higher education.

2.5 Similar Strategies Employed

CL strategies have been employed in various contexts with differing results. It should be noted that while specific techniques for how to use CL can be used as inspiration, a single technique does not adequately provide students with the environment to benefit from CL (Roselli, 2016). Therefore, previously attempted strategies will be discussed further, where a strategy represents a wider construct, one that may use various CL techniques (Roselli, 2016). Previous strategies range from a flipped classroom approach to online forms of community building, each with their own benefits and drawbacks. In an online environment, Wang (2009) identified individual accountability and positive interdependence as motivating factors that result from students working collaboratively. From this study, students reported that they enhanced friendships, developed communication and understanding between their peers, and provided an opportunity for students to take ownership over their tasks after taking part in a CL focused online environment (Wang, 2009). However, the online context of this study was determined to be more well-suited for larger groups of students when compared to that of smaller groups (Wang, 2009). On the other hand, van Vliet, Winnips, & Brouwer (2015) discussed a flipped classroom approach, where students would be presented the lecture-portion of the class prior to attending the assigned time each week. Students would then participate in group discussions and activities during the time that would traditionally have been taken up by the lecture portion of the course. The researchers found that students who participated in the flipped approach, compared to the traditional approach, identified themselves as developing critical thinking skills, task value, peer learning, and extrinsic goal orientation (van Vliet et. al., 2015). However, the authors also found that these effects were not long-lasting, finding that five months after the experience, student averages for the values of critical thinking, task value, and peer instruction were equal to that before they participated in the experience.

When conducting research into collaborative teaching, it was discovered that many literature sources used collaborative teaching synonymously with CL. Collaborative teaching, titled co-teaching in the context of this study, is operationally defined as an approach to teaching where instructors from differing academic departments work to teach a course simultaneously with one another, with the intention of expanding both student and instructor knowledge (Kim & Strimel, 2019). While there appears to be a lack of research into this specific strategy, a few studies have been conducted to develop our understanding of collaborative models of teaching. In one study, two clinical nursing courses, taught by two different instructors, were combined to create a single, co-taught course (Kruszewski, Brough, & Killeen, 2009). In this study, the instructors worked collaboratively to develop learning activities that could be used to benefit students from both classes, although the course was taught by a single instructor. From this strategy, students identified they were more confident in developing problem statements and applying the knowledge gained to their specific clinical practice (Kruszewski et. al., 2009). While the context is different, the ability to identify a problem and apply knowledge towards solving it can be generalized to the field of innovation, where students can apply their knowledge to a variety of potential problems.

Combining the benefits of both CL and co-teaching may provide students with rich, authentic learning experiences. Although collaborative teaching is an area of education that seems to lack thorough research, the findings from Kruszewski et. al. (2009) support that a co-teaching model can benefit student learning and the students' application of knowledge. CL, similarly, has been found to promote communication and critical thinking skills (van Vliet et. al., 2015; Wang, 2009). These two strategies employed simultaneously may provide students with an opportunity to develop these critical thinking skills while also furthering their abilities to apply their knowledge beyond their specific discipline.

2.6 Need for 21st Century Skills

With the many benefits and skills developed from collaborative learning, teaching, and transdisciplinary learning discussed, the need for these skills should be discussed further. There are many reasons why 21st century skills are crucial in the modern world. Kay and Greenhill (2010) identified three main shifts that have inspired the movement for these skills as 1) changes in the economy and society that have reshaped the way we live, 2) an increase in global competitiveness has United States students struggling to keep up with the rest of the world, and 3) companies shifting the way they do business due to technological and economic changes, leaving workers with more responsibility to contribute to both productivity and innovation. Defining 21st century skills can be complex, as there are multiple systems used to portray them (e.g., OECD approach from Ananiadou & Claro, 2009; or European Union, 2002); however, the Partnership for 21st Century Skills (2011) identifies global awareness, creativity, critical thinking, communication skills, contextual learning ability, and information and media literacy as key subjects and themes for student success. Students need these skills, “to successfully face rigorous higher education coursework, career challenges, and a globally competitive workforce,” (Partnership for 21st Century Skills, 2011, p. 1).

The overlap of these proposed skills for 21st century competency with those found within the collaborative learning, teaching, and transdisciplinary learning methods suggest these strategies may help develop similar tendencies within students. Preparing students for the society in which we work and live in is the responsibility of educators (Elrod, 2010). By not providing students with the opportunity to develop these skills, educators may be sending their students underprepared to face the rest of their personal and professional lives. In order to effectively provide this education, support structures are necessary and intentional strategies should be developed to promote this learning in students (Kaufman, 2013).

2.7 Self-Determination Theory and Student Motivation

Despite the apparent lack of opportunity for more transdisciplinary innovation education, the motivation of students within education presents an additional challenge. Even in situations where students are given opportunities for innovation education, how can it be shown these students are motivated to learn? This concept can be connected to the self-determination theory (SDT) of motivation, which posits that individuals have three needs, competence, relatedness, and autonomy, that dictate a person's motivation towards achieving a goal (Deci & Ryan, 2009). The SDT presents a continuum of external motivation, stemming from a lack of interest in the goal, ranging from controlled, contingent on external factors, to autonomous, identifying with the values of the behaviors towards an intended goal, while intrinsic motivation comes about from interest in the intended goal (Gagné & Deci, 2005). This continuum concerns how individuals view their competency and autonomy regarding motivation; however, the need for relatedness combined with competence are the two needs that drive individuals to internalize the values and regulations they are presented with (Gagné & Deci, 2005). Figure 1 shows the three components of SDT and how they relate to student motivation. Through the lens of education, course assignments originate as externally regulating influences on students, meaning the motivations and goals are initiated and maintained by an external source, the teacher. In this context, students are motivated to work in order to achieve an intended consequence, a good grade, or to avoid an unintended consequence, a bad grade. By providing context to students, they may begin to internalize the values and beliefs for the reason for the assignment, leading students to internally regulate their motivation without the need for external contingencies. Continuing to relate to the students and assist them in internalizing the assignment can lead to integrated regulation, the fullest type of internalization where students have a full sense that the behaviors requested are an integral part to who they are (Gagné & Deci, 2005).

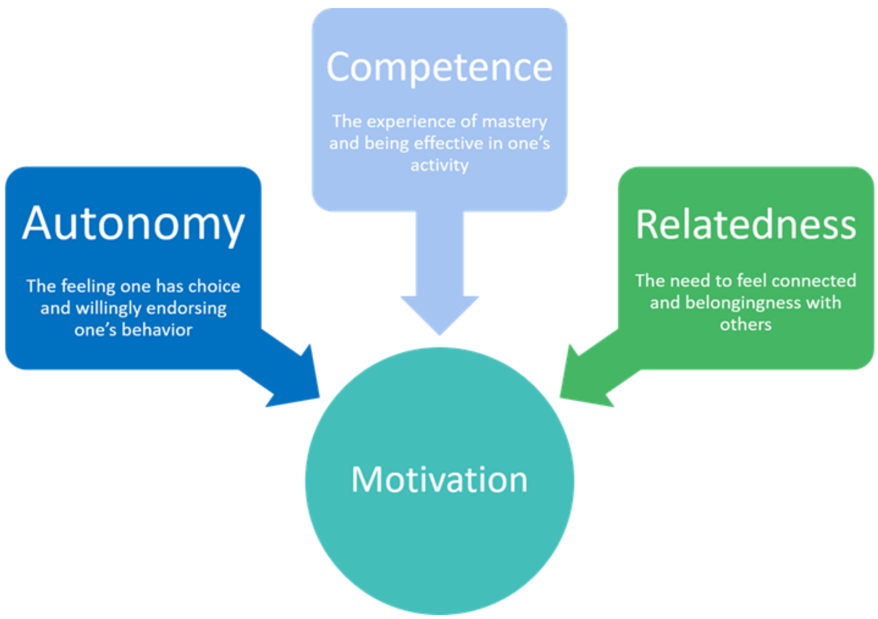

Figure 1. Self-Determination Theory Breakdown

Education traditionally begins by the instructor supplying an assignment that provides an externally regulating influence; although, the implications of technology and innovation in the modern world may alter the traditional procedures followed within the classroom. Previously, philosophy of technology was viewed almost exclusively from an academic perspective, focusing on analysis and understanding; however, modern philosophy of technology has pivoted towards a constructive view, emphasizing the need for solving practical problems in society (Brey, 2016). Finding strategies to incorporate this worldly perspective into education pushes for authentic experiences to be developed within educational settings. Authentic learning experiences is a pedagogical approach to learning where student learning is situated in the context of future use (Herrington, Reeves, & Oliver, 2013). Through a collaborative approach to learning, utilizing a co-teaching and co-learning model, in conjunction with an authentic learning experience, students may be able to discuss and understand the values presented from an assignment and assist each other in internalizing said values to progress towards integrated regulation, allowing these students to regulate their own motivation while working. Gagné and Deci (2005) identify that satisfying the needs for individuals to connect with others and to be effective in the social world support a person's ability to internalize the presented values. While there are some examples of topics that are generalized to the point of relative uniformity in opinion, more often personal opinions and interests provide bias in these settings. In this instance, providing a choice to students concerning the direction of their assignment can develop a sense of worldliness faster, thereby assisting in the internalization process. Opportunities for choosing can provide various implications for students psychologically. When students are presented with a choice, they tend to choose that which they find personally interesting while also enhancing their post-task interest (Patall, 2013). While these findings were in a situation where the choices were pre-determined, another study found that open-ended group projects, presenting ambiguous problems that required group decisions, seemed to increase motivation in students as well as higher completion rates and lower levels of plagiarism (Daniels, Faulkner, & Newman, 2002).

This literature supports that a combination of collaborative, transdisciplinary learning with authentic experiences will benefit students' knowledge and abilities. Expanding student knowledge can prepare them for their futures in the workforce, while providing means to internally motivate themselves. From here, an approach to teaching that utilizes these strategies can be developed and leveraged to supply students with the autonomy to find and solve problems the students see in the world.

2.8 Summary

This chapter attempted to explain the relevant literature that supports the research. The literature review starts by identifying information supporting the existing problem, the need for exposing students to innovation education, as well as the benefits innovation education has on students (National Academy of Engineering, 2015; Anwar, Asari, Husniah, & Asmara, 2021). Next, definitions of transdisciplinary, multidisciplinary, and interdisciplinary learning were identified and compared. The following section discusses what Social Determination Theory is, the implications it has with student motivation, and how it relates to this study. The final section discusses various strategies employed previously, identifying benefits and drawbacks of the different teaching methods. All of this is situated to help inform the development of the strategies employed for this study, which will be expanded upon in the following chapter along with the context and data sources.

CHAPTER 3. METHODOLOGY

3.1 Introduction

This chapter focuses on the specific techniques used for data collection and analysis within this study. The chapter begins by providing information about the collaborative learning model for undergraduate innovation education being studied, including the organization of the model, its appeal to students, and the unique transdisciplinary teaching and learning strategies involved. From there, the research questions are discussed and the data sources for each question are introduced and explained. The instruments used to gather the data as well as the procedures for doing so are also included. Then, the data analysis process is detailed. Lastly, any potential biases are addressed along with the strategies employed to enhance the study's trustworthiness.

3.2 Study Context: A Collaborative Learning and Transdisciplinary Model for Undergraduate Innovation Education

This study centers around understanding the influences that a novel, collaborative learning and transdisciplinary undergraduate innovation education model, referred to as the Mission, Meaning, Making (M3) model, has on student learning. The M3 model emphasizes a transdisciplinary approach that focuses on the shared practices of innovation across the academic disciplines/colleges of engineering technology, business management, and liberal arts within one large, research-intensive public university in the Midwest, as seen in Figure 2. The M3 approach to innovation education is novel as it leverages a collaborative learning strategy through its cross-college co-teaching and co-learning method that is employed to establish a campus-wide innovation community. Co-teaching is a strategy that has instructors teaching collaboratively, meaning in this case, that faculty from various colleges across the campus with expertise in design, anthropology, business development, entrepreneurship, and prototyping working together to plan and execute the core course elements within the M3 model. Similarly, the co-learning component of the model engages students from a variety of majors and backgrounds in collaborative group work with the intention of knowledge transfer occurring between students. By enabling students to use their existing knowledge through an authentic, transdisciplinary learning experience, the intention is that students will be able to communicate with their peers to apply the student's own knowledge when applicable, while interacting and learning from others in situations that may be foreign or uncomfortable with the student's personal knowledge. Co-learning occurs primarily within design teams which provides some autonomy to students, allowing students to decide who to collaborate with. However, co-learning can also occur across design teams through teams sharing progress reports to receive ideas and feedback from their peers, beyond the individual groups.

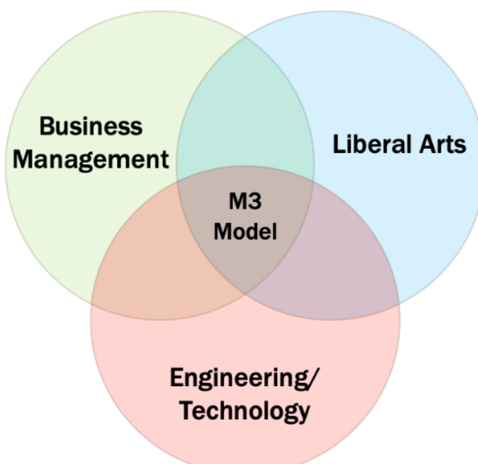

Figure 2. M3 Model Transdisciplinary Breakdown

The M3 model overall is designed to augment the way in which students learn across multiple semesters and majors rather than just serving as additional courses to add to a student's course load. Currently, some students on campus have access to similar opportunities and resources where they can learn innovation skills and capabilities, often times within engineering or technology disciplines. These "islands of innovation" often do not allow for most of the student body to have these same experiences. Therefore, the M3 model is designed to provide all students, regardless of their major, a multi-semester learning experience focused on the actual pursuit of innovation. By doing so, the goal is to afford students the space/flexibility to explore the practices of innovation and learn within the context of the student's own passions or innovation projects while they have access to campus support for activities such as, but not limited to, technology commercialization and start-up ventures.

The learning sequence for the M3 innovation model consists of five elements. First, is a disciplinary-focused introductory innovation experience that leverages the expertise of different colleges to build an "on-ramp" to innovation. Second, is a unique set of two core co-taught courses to augment the way in which students learn across multiple semesters. Within these co-taught courses students then learn from instructors and students from different colleges/disciplines as they collaboratively explore concepts such as human-centered design, ethnographic research strategies, rapid prototyping, and business development practices. This is positioned to provide opportunities for development and growth of knowledge from peer to peer, as well as between faculty, but also to create an authentic team environment composed of multiple people of varying backgrounds, knowledge structures, and general personalities. The last three elements of the M3 model include 1) a global/cultural experience to bring new perspectives into a student's innovation practices, 2) a specialization opportunity to dive deep into a skill set that may be necessary to move a student's ideas beyond the classroom to make an impact on people and communities, and 3) additional connections to the campus community for supporting outcomes such as technology commercialization, protecting intellectual property, launching startups or non-profits, and engaging in scholarship around their interests, as well as other on campus resources. The structure of the M3 model can be seen in Figure 3.

The focus of this study is specifically to analyze the influence of the two core co-taught courses that emphasizes designing and prototyping innovative solutions to problems explicitly impacting people. The first course is co-taught by instructors specializing in technology/design and anthropology. This curriculum was founded in part on Kelley's fieldwork (2016) during his "Road Trip to Innovation" experience. Kelley (2016) investigated innovation practices from corporate America and progressive engineering programs (including the design firm IDEA, Stanford's d. School, Apple Headquarters, Tesla, Google, Olin College, and Worchester Polytechnic Institute). Multiple sources in these locations suggested that "members of the 21st century workforce must advance in universal problem-solving skills, be team players, and be effective communicators to begin to contribute to the innovation space" (p.26). This led to a partnership with Anthropology for expertise in teaching students how to listen, ask, and see when exploring human-technology interactions. Jointly, this co-taught course was then created to teach students from multiple majors how to study design problems and develop innovative solutions together. The design teams in this course consist of five to eight students on average and are assigned by the instructors based on students' ratings of various customer segments that the class as a whole comes up with. The second co-taught course seeks to further explore the student-identified innovation opportunities by having instructors with expertise in prototyping/design as well as business development/entrepreneurship collaboratively guiding students through the learning experience. Students in this course work in self-assigned smaller teams (two to four students), or independently, to narrow in on the problem they are seeking to solve and go through an iterative process of prototyping in tandem with customer discovery and business model development. The goal is for students to then refine their ideas to move their solutions outside of the classroom and transform them into something that could potentially have an impact on people. Regarding this study, the focus of the investigation was specifically centered on these two co-taught courses of the M3 model. This was to better understand the influence that the collaborative learning and transdisciplinary model has on student learning. This focus on the two core courses included a population that had experiences with innovation-focused courses taught collaboratively by faculty across different colleges/disciplines. Therefore, students within the population all had a background in the basics of design and innovation and were furthering their capabilities through the collaborative learning and transdisciplinary coursework. Limiting the population to these two core courses was intentional, as the other components of the model, including the "on-ramp" introductory courses, the global/cultural, and the specialization components, are open to students outside of the M3 model. As the focus of this study is on the efficacy of this model, the researcher wanted the emphasis to remain on the students directly involved.

<table>
<tr><th>Engineering Technology</th><th>Liberal Arts</th><th>Business Management</th><th>Innovation and Technology Commercialization Community</th></tr>
<tr><td colspan="3">[redacted]</td><td rowspan="8">• University Incubators & Accelerators
• Alumni Network
• Office of Technology Commercialization
• University Makerspaces
• Student Co-working Spaces & Learning Communities
• Innovation Competitions</td></tr>
<tr><td>Design Thinking in Technology</td><td>Technology & Culture</td><td>Making the Business Case</td></tr>
<tr><td colspan="3">Core Design & Innovation Experience I*</td></tr>
<tr><td colspan="3">Co-Taught by Technology & Liberal Arts Faculty
Designing Technology for People</td></tr>
<tr><td colspan="3">Core Design & Innovation Experience II*</td></tr>
<tr><td colspan="3">Co-Taught by Technology & Business Management Faculty
Prototyping Technology for People</td></tr>
<tr><td colspan="3">[redacted]</td></tr>
</table>

Figure 3. M3 Model Structure

**Note:* *The two core design & innovation experience courses were the focus of this study and the source for all participants.*

3.3 Research Questions & Data Sources

The research questions used to guide this study were:

1. RQ1: What are the perceptions of a collaborative teaching and learning model for innovation-focused undergraduate learning, including cross-college co-teaching and co-learning, for enhancing student learning?

1. RQ2: What is the perceived influence of a collaborative teaching and learning model for innovation-focused undergraduate learning, including cross-college co-teaching and co-learning, on student abilities in *integrative learning*, *teamwork*, and *problem solving*?

3.3.1 Research Question 1 Data Sources

Semi-structured interviews were conducted with participating students as they completed the two co-taught courses within the M3 model. Participants ranged from sophomores to seniors, with the demographics of all participants from the study shown in Table 1. Recruitment of students was completely voluntary, with no benefit given to those who volunteered. Additionally, open-ended survey responses were used to supplement the findings for Research Question 1.

Table 1. Overall Participant Demographic Breakdown Data Sources

College	Number
Agriculture	4
Business Management	7
Engineering	6
Exploratory	4
Health and Human Sciences	3
Liberal Arts	14
Polytechnic	94
Science	4
Class	
Freshman	5
Sophomore	22
Junior	23
Senior	53
Gender	
Male	73
Female	72

3.3.2 Research Question 2 Data Sources

A pre-, post-, and retrospective pre-survey were developed using the validated AAC&U VALUE rubrics to assess students' self-efficacy in three specific innovation skills. The three skills include *integrative learning*, *problem solving*, and *teamwork*, all of which have been connected to innovation education. Surveys were distributed to students at the beginning and end of the two co-taught courses. Student participation was voluntary with no direct benefits given to those who chose to participate. The open-ended survey responses were once again used to supplement the findings for Research Question 2.

3.4 Data Collection

3.4.1 Research Question 1 Data Collection Methods

Scripts to recruit study participants and to conduct the semi-structured interviews were developed and given Institutional Review Board (IRB) approval. Participants were then recruited from the two co-taught courses within the M3 model, and students interested completed an IRB approved consent form. From there, interview times were arranged, and the option of an in-person or virtual interview was given to participants, depending on their preference. In-person interviews were voice-recorded and transcribed for analysis. Virtual interviews were recorded and transcribed as well, with any video footage of participants being deleted afterwards to ensure confidentiality of the participants. During the interviews, the scripted open-ended questions were posed to the participants; however, additional probing questions were asked to further develop and understand the participants' responses. Interview times ranged from 20 minutes to an hour and a half, with the advertised time as less than an hour. The interview script, including prompts given and questions asked can be found in Table 2.

Table 2. Semi-Structured Interview Script

Statement Type	Statement
Prompt	I’d like to know a little more about you. Could you provide a sentence or two about yourself: people sometimes mention their major, year in school, age, gender identity, race/ethnicity and where you're from-these kinds of things.
Question	Getting started, what was your motivation for enrolling in the Design & Innovation minor/course?
Question	What was the process like for enrolling in the Design & Innovation minor/course?
Question	Can you tell me if there were any challenges/barriers for getting started or completing it? *(Can you tell me more about that?)*
Prompt	One of the things the Design & Innovation program offers is co-teaching and co-learning from folks with different backgrounds. So, I want to ask a couple question about this.
Question	What was it like having multiple instructors from different backgrounds teaching the courses? *Probe: How did it impact your learning experience (Did it improve it and/or make it more challenging?) (Can you tell me more about that?)*
Question	What was it like co-learning with students from different major/colleges impact your learning experience? *Probe: How did it impact your learning experience (Did it improve it and/or make it more challenging?) (Can you tell me more about that?)*
Question	What was your favorite experience related to the Design & Innovation program/course? *(Can you give an example or story about that?)*
Question	What would you change about the program? How would you improve it?
Question	Would you recommend this program/course to incoming students? Why or why not? *(Can you tell me more about that?)*
Question	What other thoughts would you like to share about design & innovation education at Purdue?
Question	Lastly, from your perspective what are the most important things for preparing college graduates to be innovative?
Prompt	Please feel free to email me @ if you have any follow up thoughts or comments. Thank you!

3.4.2 Research Question 2 Data Collection Methods

A pre-, post-, and retrospective pre-survey were developed to understand student self-efficacy in the skills of *integrative learning, problem solving,* and *teamwork*. The surveys contain matrices of prompts developed from the AAC&U VALUE rubrics, which were created to evaluate student understandings of various concepts, including *integrative learning, problem solving,* and *teamwork* (AAC&U, 2009). Each of these innovation-related skills had their own matrix of 10 prompts that were sourced directly from the rubrics. The prompts given to participants were then rated by the participants on a 6-point Likert scale (i.e., '1: Not at All' to '6: Very High Degree'), asking them to determine how well the participant does or does not recognize and relate to the behaviors detailed in the prompts. The participant responses were then exported into a Microsoft Excel spreadsheet and organized to allow for analysis comparing the pre-, post-, and retrospective pre-survey results. The prompts given for each innovation skill can be seen in Appendix A. Participants were also asked to respond to a few short-answer questions on each survey to further understand their experiences and allow for additional details to be shared. The short-answer questions can be seen in Appendix B. The responses to these surveys were analyzed to understand students' self-efficacy of the three skills and the students' overall reactions to the learning experience.

3.5 Data Analysis

3.5.1 Research Question 1 Data Analysis

Upon IRB approval, semi-structured interviews of student participants were conducted. Interviews took place either in-person or virtually dependent on participant comfort. Semi-structured interviews were recorded, and subsequent audio recordings were transcribed for analysis. Transcriptions were uploaded into the qualitative analysis program NVivo to be reviewed and analyzed for any emerging themes, noteworthy statements, and general reflections of the teaching methods used within the M3 model. The researcher, along with a research team, read and listened to the transcripts to divide the participants responses into detailed codes, providing a descriptive word or phrase for each. Once coding had been completed, key words and phrases were organized further into themes, parent codes, and child codes that were connected to the research question (Saldaña, 2016). These codes were then used to identify trends in participant responses that could help answer the research question.

3.5.2 Research Question 2 Data Analysis

To answer Research Question 2, the Likert-scale survey responses were de-identified, exported into Excel, and organized to assist with the analysis process. The survey responses were copied onto a new sheet and expressed as numeric values to use statistical methods of analysis (i.e., '1: Not at All' = 1 to '6: Very High Degree' = 6). The numeric values were then put into SPSS, a quantitative data analysis software, to analyze further. A Wilcoxon signed rank test was chosen to analyze the data, as a non-parametric test was determined to be well-suited due to the ordinal data that results from Likert-scale questions. This statistical test was used to determine any differences between pre-, post-, and retrospective pre-survey data, while also testing for significant shifts of participant responses when compared to a mean at a 5% alpha level.

The open-ended survey responses were imported into the NVivo qualitative data software and analyzed for thematic codes like those used for the analysis of the semi-structured interviews of Research Question 1. These responses were also analyzed for noteworthy statements, emerging themes, or responses relating to student self-efficacy. Once coded, the instances of each code were totaled and organized for presentation and further analysis. These results were used to further understand the students' perspective of the collaborative learning and transdisciplinary model and supplement the analysis of Research Question 1.

3.6 Trustworthiness

In terms of the trustworthiness of the study, a few concepts should be addressed. Due to the researcher's involvement in the educational model being investigated, precautions were taken when conducting the interviews, analyzing the data, and developing recommendations. With the researcher being situated close to the M3 model, it is possible that the researcher affected the way the questions were perceived or asked, how the data were interpreted, and how conclusions were reached. To avoid this bias, the researcher, at multiple points throughout, member-checked the findings to ensure it accurately reflected the participants views by asking clarifying questions (Gay, Mills, & Airasian, 2017). Pertaining to the interview data as well as the open-ended survey responses, code-recode and research team peer debriefing were used by the researcher to promote trustworthiness. Regarding the Likert-scale portion of the surveys, validated rubrics were used. However, the mostly qualitative nature of the study allowed the use of data and observations from the various methods of collection to be used to triangulate the results, in hopes of gaining a more holistic understanding of the participants' perspective (Gay et. al., 2017).

3.7 Summary

This chapter begins by supplying context for the study, identifying and explaining the teaching strategies used, and how the model under investigation is set up to support student innovation education. Following the context and research questions, data sources were explained. Research Question 1 was addressed using data from semi-structured student interviews to understand the students' perceptions of the co-teaching and co-learning approaches. Research

Question 2 was addressed using Likert-scale survey responses related to the student participants' self-efficacy for innovation-related skills, including *integrative learning*, *problem solving*, and *teamwork*. The interview data were uploaded to NVivo and analyzed using descriptive coding for themes relating to research questions. The Likert-scale survey responses were statistically analyzed to understand any significant differences in participants' responses before and after their experiences within the co-taught courses. The open-ended survey responses were thematically coded and used to expand the understanding of the participants' experiences. This chapter concludes by discussing the trustworthiness of the study and any strategies used to avoid bias within the data analysis and interpretation.

CHAPTER 4. FINDINGS

4.1 Introduction

Data analyzed in this section were collected through pre-, post-, and retrospective pre-surveys administered at the beginning and end of each iteration of the two co-taught courses within the collaborative learning and transdisciplinary model for undergraduate innovation education, the M3 model. In addition, data collected from semi-structured student interviews were transcribed for analysis. The Likert-scale prompts from the surveys were uploaded to SPSS, a quantitative analysis software, and analyzed for statistical significance, if any, between the pre-survey and retrospective pre-survey, pre-survey and post-survey, as well as between the retrospective pre-survey and post-survey for each prompt. With the goal of comparing two sets of data, a non-parametric test, specifically a Wilcoxon signed rank test was used. The results were analyzed regarding the null hypothesis, that there is no statistically significant difference between survey responses for each prompt. A significance value of ≤ 0.05 was used to identify a significant difference in response, while a value above 0.05 signified an insignificant difference. A significant difference means that the null hypothesis was rejected, demonstrating that students' self-perceived abilities in the constructs of *integrative learning*, *problem solving*, and *teamwork* may have changed in response to their innovation-focused learning experience. The findings from these analyses will be presented for each research question in the following sections.

4.2 Research Question 1 Results

Research Question 1 focused on understanding the student perceptions of the collaborative teaching and learning model for innovation-focused undergraduate learning, that included cross-college co-teaching and co-learning, for enhancing the students' learning experience. To address this question, students enrolled in this model were asked to be interviewed at the end of their innovation learning experience. The results of these voluntary interviews were primarily used to help the researcher understand students' perceptions of the co-teaching and co-learning models, as well as the cross-college collaboration employed during the experience. Both alumni and current students of the model were asked to be interviewed, with a total of 12 alumni and 21 students volunteering. The demographics of interview participants can be seen in Table 3. Interviews were transcribed and then analyzed for consistent themes. To supplement this analysis, a survey that was administered to the students within the model, before and after their experiences was also analyzed. While the student surveys included many items, for this research question, the analysis focused on the open-ended questions posed to the students.

Table 3. Interview Participant Demographics

College	Current Students	Alumni
Agriculture	0	0
Business Management	2	0
Engineering	1	1
Exploratory	1	0
Health and Human Sciences	0	0
Liberal Arts	1	0
Polytechnic	16	11
Science	0	0
Class*		
Freshman	0	0
Sophomore	4	0
Junior	2	0
Senior	15	0
Gender		
Male	12	7
Female	9	5

*Note: Alumni interviewed were not asked about class ranking

These open-ended survey questions, which are provided in Table 4, differed slightly across the pre-, post-, and retrospective pre-surveys versions, but each focused on the participants describing their expectations for the learning experience, what they are/were excited for, and reflections on the quality and value of their experience. Responses were analyzed for consistent themes and used to supplement the findings from the semi-structured interviews.

Table 4. Open Ended Survey Questions

Survey	Question
Pre-Survey	Describe what you are expecting from this experience.
	Are you excited for this experience? Why or why not?
	Explain why you chose to participate in this experience?
Retrospective Pre-Survey	Describe what you expected from this experience.
	Were you excited for this experience? Why?
	Explain why you chose to participate in this experience.
Post-Survey	Describe the experience.
	Interpret the experience: explain what this experience meant to you.
	Evaluate the experience: appraise the quality, value, or the importance of this experience.
	Provide a goal statement: what will you do moving forward to continue to develop/practice these skills?

The analysis of the interviews and open-ended response data led to the identification of a series of themes which included themes relating to co-learning challenges and benefits, co-teaching challenges and benefits, and perspectives on the cross-college collaboration. In terms of co-learning, some of the themes identified for the related challenges are that working in teams is a necessary evil, meaning that group work can be frustrating, but participants identified the need for these skills, while a benefit was the diversity of knowledge present when working with a diverse group. Similarly, the themes relating to co-teaching challenges included the potential for miscommunication between instructors, while the benefits of co-teaching were acknowledged to be the wealth of knowledge from multiple instructors present, benefitting the feedback students would receive. This can indicate that the students' perceptions of the model were generally positive. While they acknowledged areas of improvement for the model, often the participant would follow up a challenge with a related benefit. Many challenges that were mentioned came from asking for recommendations for the model and were not brought up on their own accord. This could mean that students were primarily aware of the positive aspects of the model and only considered what challenges they faced when directly asked. The full set of codes for each theme as well as sample coded utterances from the participants are provided in Table 5.

Table 5. Themes Identified from Semi-Structured Interviews and Open-Ended Responses

Theme	Code	Example Coded Utterance
Co-Learning Challenges	Necessary evil	"It's really hard and it's bad... having a group work right and learning to work with people is a skill you need."
	Lack of communication and missed opportunities	"I just think that sometimes in my group I was not heard... it was frustrating because I thought we had other very innovative ideas but other members of the group wanted to take the easy route."
Co-Learning benefits	Diversity of knowledge in teams	"The fact they're from different backgrounds makes it that much better, I think, because they all have something new to bring to the table."
	Enhances brainstorming	"It's really helpful just because you have [more] people for you to like bound ideas off of and they obviously will have like a different outlook and perspective."
	Learning from others outside of your own group	"It was nice because no one in our group was really good at [Computer Aided Design tools]... but our instructors helped us with that a lot, but there were students in the class who were familiar with that, and they were more than willing to help us and let us use their 3D printers."
Cross-College Collaboration	Applying existing knowledge while in college	"Applying what you've learned is [pretty] cool... it's not very often you get to do that in college because like calculus is stupid. So, applying like my CAD tools like that, it was a feel-good experience."
	Interacting with people you would not normally meet	"The majority of the people that I know are business majors, so it's nice... just meeting other people out of the major, but then beyond that... they have different skill sets than what I have that compliment and we can complement each other."
Co-Teaching Challenges	Miscommunication between instructors	"It was something logistic related like when we were turning something in, and it was literally just [Instructor 1] said oh yeah this is due next Monday. And then [Instructor 2] goes, actually I think it's due next Wednesday or something."
	Online information discrepancies	"I think for co-teaching... the communication of information is difficult because I go on [online course resource] and it seems like there are two different goals that we're trying to fulfill."
Co-Teaching Benefits	Differing areas of expertise to supplement learning	"I really like getting both of their perspectives and I like the way they split up the class. So that like [Instructor 1] would speak about [the] human aspect of it and then [Instructor 2] would [tie] it all together [with the technology expertise]."
	Various perspectives for feedback	"I actually think it's awesome... having [different] people that we can go to is really nice in a design thing when like, there's going to be different kinds of inputs and mindsets."
	Benefits of different teaching approaches	"They [co-teaching faculty] might teach the same courses but they teach it differently, and the way you might understand it from somebody else you might not understand it from another person."

4.3 Research Question 2 Results

Research Question 2 focused on understanding students' perceived influence of a collaborative teaching and transdisciplinary model for innovation-focused undergraduate learning, that included cross-college co-teaching and co-learning, on the students' innovation-related abilities (i.e., *integrative learning*, *problem solving*, and *teamwork*). To address this question, student responses to pre-, post-, and retrospective pre-surveys that were administered to the enrolled students at the beginning and end of each semester were analyzed. From the three semester iterations of the model's co-taught courses (Spring 2021, Summer 2021, and Fall 2021), 150 students completed both the pre- and post-/retrospective pre-surveys. These surveys included both the 6-point, Likert-scale responses (i.e., '1: Not at All' = 1 to '6: Very High Degree' = 6), and the open-ended responses. In the following sections, the analysis results of the student survey responses will be presented according to each innovation skill construct.

4.3.1 Integrative Learning

Within the *integrative learning* construct, it is separated into five sub-constructs with two prompts per sub-construct. These sub-constructs include Connections: Experience, Connections: Discipline, Transfer, Integrated Communication, and Reflection and Self-Assessment. The definitions of these sub-constructs can be seen in Table 6. Each prompt was analyzed comparing the pre- and retrospective pre-surveys, the retrospective pre- and post-surveys, as well as the pre- and post-surveys. Each prompt, along with the related analysis outcomes, can be found in Appendix C. The analysis in this appendix is organized into separate tables based on the individual semester iterations of the courses as well as for all the students overall. The overall analysis includes every participant who filled out all three surveys, and most of the important findings for this study stem from this overall analysis of the model. For each survey prompt, the mean rating for both compared surveys were identified, as well as the z-score, significance value, and whether the response would reject or retain the null hypothesis. Regarding the comparison between the pre- and post-surveys for the overall model, of the ten 6-point Likert-scale prompts, all ten prompts rejected the null hypothesis, meaning there was a significant difference in students' self-perceived abilities in in*tegrative learning*, with the mean of the responses moving from 4.36 to 4.99. The largest change in responses relates to prompt 3 which is, *I can independently create a whole out of multiple parts.* This change saw an increase in the student rating on the prompt from 4.20 to 4.98 with a shift of 0.78. Alternatively, the smallest shift is from prompt 9, *I can envision a future self*, with a statistically significant positive shift of 0.43.

Continuing the analysis of the overall program, when comparing the retrospective pre- and post-surveys for the *integrative learning* construct, eight of the ten prompts resulted in significant positive differences. The two prompts that retained the null hypothesis and did not show significant shifts were prompt 7, *fulfill assignments by choosing a format, language, or graph that enhances meaning,* and prompt 8, *make clear the interdependence of language and meaning, thought, and expression.* Despite not being significant, both prompts did have positive shifts from retrospective pre- to post-survey, with prompt 7 having a change in means from 4.61 to 4.81. Similarly, prompt 8 had a positive shift, despite retaining the null hypothesis, from 4.75 to 4.80.

When looking at the analyses from the different semester iterations of the courses, Spring 2021 did not have a pre-survey as the research began midway through the semester. As a result, the retrospective pre- and post-surveys were analyzed for significance. A Wilcoxon Signed-Ranks Test indicated that mean responses to each *integrative learning* prompt on the post-surveys were statistically significantly higher than the mean responses on the retrospective pre-survey. The largest difference from post to retrospective pre-survey was found in prompt 4, *I can draw* *conclusions by combining examples, facts, or theories from multiple fields of study or perspectives*. This change saw an increase in the student mean rating on the prompt from 4.39 to 5.18, with a shift of 0.79. The smallest significant positive shift of 0.5 was from prompt 1, *I can synthesize connections among experiences outside of the formal classroom*.

Table 6. Definitions of Integrative Learning Sub-Constructs

Sub-Construct	Meaning
Connections to Experience	Meaningfully synthesizes connections among experiences outside of the formal classroom to deepen understanding of fields of study to broaden own points of view
Connections to Discipline	Independently creates wholes out of multiple parts or draws conclusions by combining examples, facts, or theories from more than one field of study or perspective
Transfer	Adapts and applies skills, abilities, theories, or methodologies gained in one situation to new situations
Integrated Communication	Fulfills the assignment(s) by choosing a format, language, or graph in ways that enhance meaning
Reflections and Self-Assessment	Demonstrates a developing sense of self as a learner, building on prior experiences to respond to new and challenging contexts (may be evident in self-assessment, reflective, or creative work)

Note: Definitions are from "VALUE Rubrics – Problem Solving", by AAC&U (2009)

For the Summer 2021 iteration, there were only 12 students who completed the surveys. This limited number of participants does not enable a Wilcoxon Sign-Ranks Test. However, these data were included in the overall analysis, but an individual iteration analysis was not able to be completed.

Moving on to the Fall 2021 iteration, a Wilcoxon Signed-Ranks Test indicated that man responses to each *integrative learning* prompt on the post-surveys were statistically significantly higher than the median responses on the pre-survey. The largest difference was observed in prompt 2, I *have a deepened understanding of fields of study to broaden my own points of view*. This prompt saw a statistically significant shift in the students' mean rating from 4.22 to 5.02, with a shift of 0.8. Inversely, the smallest statistically significant positive shift of 0.39 comes from prompt 5, *I can adapt and apply skills, abilities, theories, or methods gained in one situation to new situations*.

4.3.2 Problem Solving

As for the *problem solving* construct, it is separated into six sub-constructs with one to three prompts per sub-construct. These sub-constructs include Define Problem, Identify Strategies, Propose Solution/Hypotheses, Evaluate Solutions, Implement Solutions, and Evaluate Outcomes. The definitions for these sub-constructs can be seen in Table 7. The results were analyzed the same way as the *integrative learning* construct, comparing the pre- and retrospective pre-surveys, the retrospective pre- and post-surveys, as well as the pre- and post-surveys, and resulted in the same identifying values. All ten prompts and the associated analysis can be seen in Appendix D. When comparing the pre- and post-surveys for the overall model, all ten prompts resulted in the null hypothesis being rejected, showing a statistically significant shift in students' self-perceived *problem solving* abilities with the mean of all responses shifting from 4.40 to 5.05 when comparing the pre- and post-surveys for the overall model. The largest positive shift comes from prompt 3, *I can propose one or more solutions/hypotheses that indicates a deep comprehension of the problem.* This prompt had a statistically significant shift of students' mean rating from 4.27 to 5.11, with a positive shift of 0.84. The smallest statistically significant positive shift is from prompt 9, *I can review results thoroughly*, with a shift from 4.47 to 5.17.

Table 7. Definitions of Problem Solving Sub-Constructs

Sub-Construct	Meaning
Define Problem	Demonstrate ability to construct a clear and insightful problem statement with evidence of all relevant contextual factors
Identify Strategies	Identifies multiple approaches for solving the problem that apply within a specific context
Propose Solutions/ Hypotheses	Proposes one or more solutions/hypotheses that indicates a deep comprehension of the problem. Solution/hypotheses are sensitive to contextual factors
Evaluate Potential Solutions	Evaluation of solutions is deep and elegant and includes, deeply and thoroughly, all of the following: considers history of problem, reviews logic/reasoning, examines feasibility of solution, and weights impacts of solution
Implement Solutions	Implements the solution in a manner that addresses thoroughly and deeply multiple contextual factors of the problem
Evaluate Outcomes	Reviews results relative to the problem defined with thorough, specific considerations of need for further work

Note: Definitions are from "VALUE Rubrics – Problem Solving", by AAC&U (2009)

Furthering the analysis of the overall program and comparing the retrospective pre- and post-surveys for the *problem solving* construct, similarly, all ten prompts resulted in significant positive shifts. The largest difference was seen from prompt 4, *I can propose solution/hypotheses that are sensitive to contextual factors,* with a shift from 4.52 to 5.05. The smallest positive difference in means, while still significant, was from prompt 10, *I can use results to inform potential future work*, with the means changing from 4.75 to 5.17.

Analyzing the *problem solving* construct by iteration, the Spring 2021 comparison between retrospective pre- and post-surveys resulted in all ten prompts showing statistically significant positive shifts, with the mean responses from retrospective pre- to post-survey going from 4.58 to

5.05. The largest shift comes from prompt four, *I can propose solutions/hypotheses that are sensitive to contextual factors*, which saw a statistically significant positive shift from 4.5 to 5.3, with a difference of 0.8. The smallest statistically significant positive shift of 0.33 comes from prompt two, *I can identify multiple approaches for solving the problem*. Summer 2021, as stated above, was not analyzed individually due to the small sample size, with the data being incorporated into the overall analysis. For Fall 2021, all ten prompts resulted in statistically significant positive shifts between the pre- and post-surveys. The largest significant positive shift saw a change in means from 4.34 to 5.16, with a shift of 0.82 from prompt three again, while the smallest significant positive shift was from prompt 5, *I can be conscious of ethical, logical, and cultural dimensions of the problem when proposing a solution*. This prompt saw a change in means from 4.56 to 5.02, with a significant positive shift of 0.46.

4.3.3 Teamwork

Lastly, for the *teamwork* construct, it is separated into five sub-constructs with one to three prompts per sub-construct. These sub-constructs include Response to Conflict, Constructive Team Climate, Individual Contributions, Facilitating Team Member Contributions, and Contributing to Team Meetings. The definitions for these sub-constructs can be found in Table 8. The same analysis that was conducted for *integrative learning* and *problem solving* was used to analyze the *teamwork* construct, comparing the pre- and retrospective pre-surveys, the retrospective pre- and the post-survey, and the pre- and post-surveys. Tables with each iteration as well as overall analysis for the *teamwork* can be found in Appendix E. When comparing the responses of the pre- and post-survey for the model overall, only one of the ten prompts rejected the null hypothesis, showing a statistically significant positive shift. Prompt 1, *I can address destructive conflict directly,* had a change in student rating from 4.16 to 4.75, showing a significant positive shift of 0.59. Of all the insignificant shifts, two prompts had negative shifts, with prompt 3, *I can treat team members with respect*, showing a pre- to post-survey shift from 5.42 to 5.39, with a negative shift of 0.03. The second negative prompt was prompt 6, *I can complete all assigned tasks thoroughly and by the deadline*, which shifted from 5.19 to 5.03, showing an insignificant negative shift of 0.16.

Table 8. Definitions of Teamwork Sub-Constructs

Sub-Construct	Meaning
Responds to Conflict	Addresses destructive conflict directly and constructively, helping to manage/resolve it in a way that strengthens the overall team
Fosters Constructive Team Climate	Supports a constructive team climate by treating team members with respect, using positive vocal or written tone, motivates teammates by expressing confidence, provides assistance and/or encouragement
Individual Contributions Outside of Team Meetings	Completes all assigned tasks by deadline; work accomplished is thorough, comprehensive, and advances the project
Facilitates the Contributions of Team Members	Engages team members in ways that facilitate their contributions to meetings by both constructively building upon or synthesizing contributions of others as well as noticing when someone is not participating and inviting them in
Contributes to Team Meetings	Helps the team move forward by articulating the merits of alternative ideas and proposals

Note: Definitions are from "VALUE Rubrics – Teamwork", by AAC&U (2009)

When comparing the retrospective pre- to post-survey for the overall program, interestingly, nine of the ten prompts resulted in statistically significant positive differences. The one prompt to retain the null hypothesis, thus showing an insignificant difference, was prompt 6, which had a positive insignificant shift in means from 4.88 to 5.03. Of the rest of the significant differences present, the largest positive difference of 0.43 came from prompt 5, *I can provide assistance and/or* *encouragement to the team,* with means changing from 4.91 to 5.34. The smallest difference, while still significant, was from prompt 2, *I can be helpful in managing and resolving conflict in a way that strengthens the team*, with a positive difference of 0.3, shifting from 4.58 to 4.88.

Similar to the other two constructs, the Spring 2021 iteration compared the retrospective pre- and post-surveys for the *teamwork* construct as well. Interestingly, this resulted in all but one prompt, prompt six, showing statistically significant positive shift. The largest significant shift came from prompt nine, *I can notice when someone is not participating and invite them to engage*, with change in mean ratings from 4.53 to 5.08, showing a positive shift of 0.55. The smallest statistically significant positive shift was from prompt two, *I can be helpful in managing and resolving conflict in a way that strengthens the team,* changing means from 4.57 to 4.85, with a positive significant shift of 0.28. Summer 2021 was once again not analyzed individually due to the small sample size. Fall 2021 resulted in zero of the prompts showing statistically significant shifts. Of these insignificant shifts, prompt six had the largest negative shift of 0.15, with means changing from 5.25 to 5.10, while the largest positive shift came from prompt one, which had a change in means from 4.24 to 4.82, showing a positive insignificant shift of 0.58.

4.4 Summary

Over the three iterations of the co-taught courses within the collaborative learning and transdisciplinary innovation education model, students' self-perceived skills in the constructs of *integrative learning*, *problem solving*, and *teamwork*, along with the students' perspectives on the model, were collected to provide insight toward this study's research questions. Students were asked to fill out a pre-, post-, and retrospective pre-survey at the beginning and end of their innovation-focused learning experience, as well as asked to volunteer to be interviewed. From the semi-structured interviews, various themes were coded including co-learning being a necessary evil while also giving more perspectives for activities such as brainstorming, co-teaching allows for more diversity of teaching styles to benefit the students but can cause confusion due to miscommunication, and cross-college collaboration allowing for students to share knowledge and practices with each other. The Likert-scale responses from the surveys were used to identify significant shifts, if any, for the three innovation constructs of *integrative learning*, *problem solving*, and *teamwork*. From the Wilcoxon Signed-Ranks analysis of the overall model, comparing the pre- to post-surveys, 21 of the 30 prompts, ten coming from each construct, resulted in statistically significant positive shifts. The nine insignificant shifts all came from the *teamwork* construct, which the potential reasoning for these outcomes will be discussed further in Chapter 5, along with other conclusions from these findings and recommendations for this model and future research.

CHAPTER 5. CONCLUSION, DISCUSSIONS, & RECOMMENDATIONS

5.1 Introduction

In Chapter 4, the findings of the survey responses and themes coded from the semi-structured interviews were stated. Following this analysis of responses, conclusions to the research questions will be made and a discussion of the results are provided in this chapter. In addition, recommendations for future research as well as ways to improve educational practice will be provided.

5.2 Conclusions of the Study

The purpose of this study was to 1) understand the perceptions students held of the cross-college co-teaching and co-learning model for undergraduate innovation education, as well as 2) identify significant shifts in students' self-efficacy in relation to innovation skills (i.e., *integrative learning, problem solving*, and *teamwork*). This study used two distinct data sources to address the study's research questions which were semi-structured interviews with students and alumni of the educational model as well as pre-, post-, and retrospective pre-surveys containing both Likert-scale and open-ended questions. These data sources were selected to develop a rich understanding of the learning experiences of the participating students and the influence of these experiences on the participants' perceptions of their innovation abilities. 21 students and 12 alumni were interviewed, and 150 surveys were analyzed.

In regard to Research Question 1, what are student perceptions of a collaborative teaching and transdisciplinary model for innovation-focused undergraduate learning, including cross-college co-teaching and co-learning, for enhancing student learning, several themes were found.

These themes included 1) co-teaching benefits like the differing areas of expertise the faculty have to offer, the multiple perspectives they can supply for feedback, and the benefits different teaching approaches have for students, 2) co-learning challenges such as a lack of communication leading to poor design choices and teamwork being a necessary evil, 3) co-learning benefits including the diversity of knowledge on teams, enhanced brainstorming, and knowledge transfer both within and outside of design teams, 4) cross-college collaboration and how it allows for applying existing knowledge in new contexts as well as gives students the chance to interact and network with people they may have not met otherwise, and 5) co-teaching challenges such as discrepancies in online information and miscommunication between instructors. All these themes can indicate that students found this model more helpful than hindering when it comes to their learning, identifying more positive outcomes of the cross-college co-teaching and co-learning model than challenges. However, many of the challenges identified by participants were followed with an acknowledgement of the benefits it provided. The best example of this relates to working in teams and it being a necessary evil. Participants stated that, "*[working in teams is] really hard and it's bad... having a group work right and learning to work with people is a skill you need*." This statement shows that while students may not enjoy working in teams, they can identify the need for these skills. Despite these slight negatives, the many benefits identified can suggest that the transdisciplinary approach allowed for an authentic environment to be developed, one that students identified as enabling them to apply their content-specific knowledge and build up a network of support.

Research Question 2 sought to understand the perceived influence of a collaborative teaching and transdisciplinary model for innovation-focused undergraduate learning, including cross-college co-teaching and co-learning, on student abilities in *integrative learning, problem* *solving*, and *teamwork*. The analysis revealed that 21 of the 30 prompts, ten from each of the three constructs, showed statistically significant positive shifts when comparing the pre- and post-surveys from before and after the coursework, with the nine insignificant shifts coming from the *teamwork* construct. This can indicate that students felt growing confidence in consistently in both *integrative learning* and *problem solving* skills. However, the lack of significant differences in the *teamwork* construct could be influenced by a few factors. Some influences could be related to their preconceived perspectives on group work from prior experiences, the interactions they had with their design teams within the two cross-college, collaboratively taught core courses, existing confidence the students had in their teamwork abilities, or other external factors that influenced their experience.

The results of the study can hopefully shed light on the efficacy of a cross-college, collaborative teaching model on developing students' innovation capabilities. These results can also be positioned to inform future iterations of this model, the development of similar models in other contexts, as well as future research that could be conducted to further innovation capability knowledge. These results will be used to inform further discussion and future recommendations below.

5.3 Discussion of Results

Based on the analysis found in Chapter 4, the resulting outcomes were used to inform the following discussion. Implications of the results and further recommendations will be discussed throughout the remainder of this chapter.

5.3.1 Research Question 1 Discussion

Research Question 1 sought to understand the students' perceptions of the collaborative model of teaching and learning employed during the model. This was achieved by conducting semi-structured interviews following the experience, with the resulting transcripts coded and analyzed for themes that were able to provide insight into the student experience. One theme that emerged was the co-learning aspect, having students work collaboratively with students from differing majors/academic backgrounds, emulating a realistic experience to that of the real world. One student participant stated, "*when you get out of school, you got to be able to communicate and get information from a bunch of different groups of people right, even when you're not always going to be working with the same person.*" This can highlight the authentic learning environment that students find themselves a part of during the model. By combining aspects of collaborative, transdisciplinary, and problem-based learning, participants found themselves engaging with people they wouldn't normally have a chance to meet. This combination of participant educational backgrounds was also highlighted to benefit the brainstorming and ideation process, with one participant saying, "*we came from different backgrounds… we knew what we were doing in our different fields. So, it's nice when we had the brainstorming days, we would have like 100 plus ideas, because we were all over the place.*"

Furthering the discussion on the benefits of an authentic learning environment, multiple participants discussed how the M3 model allowed them to meet people they would not have met otherwise. For example, one participant stated, "*now I've met people in different majors, and made friends with people that I wouldn't have normally met,"* which can be a beneficial by-product of this model. While the collaborative model is primarily intended to promote integrative thinking and knowledge transfer, this benefit, that transcends outside of an educational setting, can provides additional merit to the efficacy of the model. Meeting people is not only a social benefit, but one participant identified the potential professional connections that were made, saying, "*it has become like an entire experience… and [I] have those people in my corner that I can contact if needed.*" Building relationships that can be mutually beneficial in multiple contexts may provide another layer of value developed from this model. As this model aims to develop an authentic learning environment for students, having this expansion of a student's network aids in this process. Considering that many individuals will enter the workforce and find themselves interacting with people from various backgrounds where they will need to learn to be flexible and adapt to situations, allowing them to engage in a similar practice while in school can help them to develop strong communication and collaboration skills. This growing network also connects with the self-determination theory and how relatedness is a factor that contributes to an individual internalizing motivation.

When asked about the co-teaching aspect of the model, participants highlighted that having multiple instructors for the same class helped the students to understand concepts they may have previously struggled with. The different teaching styles presented helped engage students with varying learning styles, with a student mentioning, "*they [co-teaching faculty] might teach the same courses, but they teach it differently, and the way you might understand it from somebody else you might not understand if from another person.*" By having instructors work collaboratively to teach a course, it allows a broader range of students to understand the concepts at a deeper level. Not only does it increase the instructor to student ratio, allowing for more individualized teaching, but it also helps students who may have differing approaches to learning to learn the topics easier.

Generally, participants acknowledged a development in their confidence to both complete a task and to use a variety of tools and resources for prototyping ideas. Example statements about this new confidence includes, "*I had never really seen myself as tech savvy, but these classes made me feel a lot more confident,"* and, "*this experience… taught me how to become a better thinker, innovator, and designer of technology for people."* By helping students develop their competencies and confidence, many students referenced their future careers and how this model gave students the time and opportunity to succeed. Many students that participated had never experienced a class with a required lab component or any sort of hands-on, project-based learning assignments in college, granting these students new knowledge and experiences they may not have received within their majors. Some participants identified the ability to translate these learned skills to their future careers, such as, "*This experience was important to me for my future career (speech pathologist) where I will need to be empathetic of situations that can differ from my own.*" Others identified that specific skills may not transfer to their careers, but the innovation mindset will, with one student saying, "*As a logistics intern, I probably won't be doing as much like design work… this class really made my creative juices flow a lot more than I think other classes that I've taken.*" As these skills have been identified as important for individuals entering the workforce in the 21st century, the fact students are identifying their own growth will hopefully allow them to enter their careers confidently and able to contribute effectively. These developed confidences also seemed to have an impact on participants' career goals. Specifically, career siloes that may have existed previously were broken down, allowing students to see how their learning can be applied different careers than what they expected, with one participant saying, "*being able to talk through that project and prove that organizational leadership and that project management aspect works in an actual innovative setting... combining it with supply chain is pretty much the trifecta, like, pretty much everywhere that I have interviewed with or talked to… was really interested in that*." While students are developing confidence, there remains an opportunity to research the need for these skills in the workforce and whether these students are retaining this confidence as they begin their careers. Defining innovation within industry can be challenging but supplying students with the knowledge and tools to be innovative will hopefully benefit these fields.

5.3.2 Research Question 2 Discussion

Research Question 2 used pre-, post-, and retrospective pre-surveys that included 6-point Likert-style responses as well as open-ended questions to understand students' self-efficacy in three innovation focused constructs. These three constructs of *integrative learning*, *problem solving*, and *teamwork* encompass skills identified as beneficial to the workforce and can be connected to the 21st century skills. Focusing on the construct of *integrative learning* to start, in all iterations of the model (Spring 2021, Summer 2021, and Fall 2021), with the exception of Summer 2021, most of the prompts rejected the null hypothesis, indicating a significant positive difference in participants' self-efficacy. Supplementing these findings, participants identified in the interviews and open-ended responses that they will use *integrative learning* skills after the class. One participant said, "*this experience was important to my future career, where I will need to be empathetic of situations that can differ from my own*," while another mentioned, "*it is a great experience that can be applied across many different fields and alternative scenarios*." Both quotes can show the ability of students to apply knowledge from various areas into a single context, enabling *integrative learning* to occur.

Summer 2021 had a rather small number of participants (N = 12). However, there were important insights from this online iteration of the model's coursework. As the model employs a problem-based learning approach, the hands-on component of the courses provides great benefit to students and their learning. During the online summer iteration, students were sent kits of components to help supplement their learning as well as provide them with an experience like that of the more traditional, in-person iterations. These kits included components for the multiple prototyping activities done in the first few weeks of the more traditional iterations (i.e., soft robotic grippers and silicon mold making, microcontroller programming and wearable technology, CAD modeling and 3D printing, and more) and dial calipers, multiple sensors, electrical components, and other items that would not traditionally be found in a student's home. All these items were used to help teach the students different methods of prototyping, while providing them with additional components that they may use when developing their own prototypes. However, it is expected both the online aspect, as well as the accelerated nature of the summer semester, may have lessened the experience for these students.

Investigating the *problem solving* construct, like *integrative learning*, the summer iteration resulted in none of the prompts showing significant shifts, due to similar reasons as stated above. For the other iterations, when investigating the *problem solving* construct by comparing the retrospective pre- and post-surveys for Spring 2021 and the pre- and post-surveys for the other iterations (excluding the summer iteration), every prompt resulted in a significant positive difference. Considering that overall, for the model, as well as the individual iterations, students expressed significant differences in their *problem solving* abilities, the model can show to have some merit toward developing these capabilities within students. Participants also stated supporting evidence in the open-ended survey responses and interviews, with one saying, "*[I will] use the skills from this course to make better solutions for any problem*," highlighting the ability to solve problems as a benefit.

Interestingly, the *teamwork* construct had only a single prompt showing a significant difference when comparing the pre- and post-surveys for the model overall. However, when comparing the retrospective pre- to post-surveys, eight of the ten prompts resulted in significant positive differences. This could be related to a few factors, the first of which is that students may have felt confident in their teamwork skills coming in to these courses due to their prior experiences with teams. Working on group assignments within a student's discipline could mean working with peers of similar mindsets or personalities. This homogeneity in teams could result in less conflict or dissenting opinions when it comes to decision making. Because of this, students may feel that they are competent when it comes to working in teams, only to find out that working in a more authentic, transdisciplinary team can be much more challenging. With diverse perspectives and backgrounds working in a single team, there is potential for conflict to arise or for personalities to clash when compared to a less diverse group. Students may have acknowledged these challenges after going through the experience, thus, participants may have rated themselves slightly lower on the retrospective pre-survey than they did on the pre-survey, before the experience. This would also mean that the participating students could feel more confident in their teamwork abilities when working in a truly transdisciplinary environment.

When looking at the pre- and post-survey comparison for the Summer and Fall 2021 iterations, they also had no significant shifts found. The interesting thing to note is because the Spring 2021 iteration did not have a pre-survey, the comparison of retrospective pre- and post-surveys resulted in all but one prompt showing a significant difference, with the single insignificant change coming from prompt 6, *complete all assigned tasks thoroughly and by the deadline*. There are a few reasons why this lack of significant shifts could have occurred. First, there is a chance that students in the Spring 2021 iteration rated themselves more accurately on the retrospective pre-survey because they were able to acknowledge their abilities when filling out the following post-survey before thinking critically about where they were at the beginning of the class. This would mean that students are potentially more accurately acknowledging their strengths when it comes to *teamwork* when completing the surveys after their experience. This would mean that the data and comparing the pre- and post-surveys for the overall model may be skewed due to participants inaccurately rating their self-efficacy during the pre-survey.

There are some positive shifts in the *teamwork* construct that should be highlighted. First, the only prompt from the overall model analysis to reject the null hypothesis was prompt 1, *address destructive conflict directly*. Students work in teams almost entirely throughout the entire model, and while many have negative opinions on teams, often it stems from a negative experience they had previously had. One participant stated, "*I was not excited to take this course because I have had bad experiences working with teams in the [pre-requisite] for this class,"* but many students mentioned learning to be a better teammate, with one saying in the open-ended responses, "*I plan to enter my future education/career with a better drive to problem solve while working with others."* Having so much experience working with others could have also taught many of these skills to the students already, potentially causing the pre-survey responses to be higher than those of the other constructs. Even with the lack of significant shifts, all but prompt 3, t*reat team members with respect*, and prompt 6 increased in mean from pre- to post-survey, but not significantly. The pre- and post-survey means for each prompt overall can be seen in Table 9.

Table 9. Teamwork Overall Pre- and Post-Survey Means

Prompt	Pre-Survey Mean	Post-Survey Mean
1	4.16	4.75
2	4.61	4.88
3	5.42	5.39
4	5.12	5.33
5	5.12	5.34
6	5.19	5.03
7	4.89	5.14
8	5.94	5.22
9	4.55	4.97
10	4.88	5.15

There is another potential factor influencing this lack of significant differences which is students' opinions on *teamwork* in general. There are many examples of participants discussing, in either the open-ended responses or the interviews at the end of the semester, how they did not enjoy working in teams. One student stated, "*it would be good to address how to deal with teammates that are not pulling their weight,*" in the open-ended responses when asked for recommendations. Having a poor experience, whether in other classes or this specific model, may have resulted in participants rating themselves lower on the post-surveys in these various constructs. There is also the potential that participants overestimated their own abilities going into the model, only to discover that they do struggle with inter-team conflict management or communication. Considering many participants made references to having worked in teams in previous educational experiences, such as, "*I've been in a lot of groups where nobody wants [to work],*" students most likely have preconceived ideas about how they would handle different situations from their prior experiences.

5.4 Recommendations for Educational Practice

The first recommendation for those interested in developing and implementing collaborative and transdisciplinary models for undergraduate innovation education stems from the summer iteration of the model - where the experience was impacted by the online and accelerated nature of the course. The courses were taught in 4-week, online cycles instead of the traditional in-person 16-weeks. Some students stated in their open-ended responses that the accelerated fashion helped them learn, while many felt it hindered their learning, with one student participant saying, "*since it was condensed, I think that some phases were quite rushed and there was a maddening pace at the beginning and then slowed down to a crawl after a certain point.*" Reducing the allotted time to a quarter did not allow for the iterative process of design to take full form, resulting in student projects being rushed and not allowing ample time for customer interviews, user feedback, and many other aspects of the process. To counteract this, a summer iteration could take at least 6 weeks, still less than half the standard semester time, but could allow for more opportunities for students to develop their projects. Sending the students kits of materials to assist in learning the prototyping process and development of their products certainly aided them in their process; however, more time could be taken to develop documents and additional resources that could be included in these kits to help assist students when attempting to work with components they may have little to no experience with. During the traditional iterations, these issues can be resolved by working with an instructor or teaching assistant (TA) for the course, but the distance and online nature limits this avenue as a means to understanding these issues. Additional resources may not be a direct replacement for this individualized instruction but may help supplement the instructor's online involvement in a way that could help support the students to succeed during the course.

Multiple participants made statements relating to their opinions on team formation, both highlighting benefits and challenges of the two strategies for team formation used in the model. For the first core design course, the class, as a whole, identifies as many customer segments as possible. Students then individually rate their top choices for customer segments. Based on these ratings, students are placed into design teams by the instructors. For the second core design course, students pitch their product ideas to each other and then can choose to work with someone who has a good idea, or independently if no other students resonated with the pitched idea. Team formation is challenging in most situations, however, in this transdisciplinary context, it is more beneficial to have students working in teams with a variety of majors. In the first core design course, having the instructors decide the teams can allow for this diversity of majors to exist, whether intentional or not. Although, participants identified that working in these chosen teams can often be challenging when the student does not feel like they fit in. This could be due to a few factors; one being differing personalities being present on the team. The instructors for this course inform students that they should all take a personality test and discuss the outcomes with the rest of the team, highlighting that groups should be intentional about including everyone, particularly students who are more introverted. This helps to engage students with each other and identify strengths and weaknesses when it comes to working together, although participants still mentioned feeling left out due to being quieter than the rest of the team. One method of counteracting this was to use modern technology to communicate effectively outside of class. While personality still impacts students beyond the classroom, interacting using tools such as Microsoft Teams, GroupMe, Slack, or other team communication programs can give these quieter students more opportunity to speak up in a less direct manner. While this can help promote inclusion and communication, it should still be explained to students the impact different personalities can have on teams and that everyone should be intentional with making sure that the thoughts and opinions of every group member are heard.

Another recommendation that participants brought up was the inconsistency in the timeline of the model as well as the grading. Because the students primarily worked in teams, most of their assignments were turned in as a group. This led to one grade often being assigned to all students of that design team. While this strategy worked most of the time, there were instances where participants mentioned feeling that the distribution of work between group members was unfair and that their grades should reflect the amount of work being done. One participant said in their interview, "*it makes your life very difficult because you have to depend on those people to make sure the job is getting done, right? If nothing is getting done, your grade is going to suffer, but you* *also can't just go ahead and do everybody's work, that's unfair to you.*" This can highlight the inequity that can occur when students work in groups. In both courses, students are told at the beginning of the semester that they need to make a team charter, a document that details how they intend to organize their team, including disciplinary actions for members not doing their parts. This is typically effective at keeping students working cohesively, but in some circumstances, group members stop showing up to class or become increasingly hard to reach, creating frustration and anxiety for their active team members. Currently, students are not asked at the end of the semester to rate their team members as may be done in other classes. However, adding some sort of end of semester team evaluation grade could help provide those students who did a lot of the work, as stated by their peers, a benefit to their grade while inversely, those students who are stated to have done less work, may have a slight reduction in their grade. It could also be possible to have a system for each group assignment that does something similar, but a part of the learning experience of the model is adapting to inter-team conflict and being able to navigate to a solution effectively.

Autonomy is given to students throughout this model. Students are given the opportunity to form their own teams, identify their own problems and create their own solutions, and complete tasks and assignments, for the most part, at their own rate. This autonomy presented to students can help motivate them, as stated in the self-determination theory, but it also creates some issues when it comes to deadlines within the model. While students are given general deadlines for assignments, due to the iterative process they go through, students will often change projects, or directions for their current projects, midway through the semester. The instructors often allow for resubmission of assignments to improve their grades or to adjust to a new project direction; however, this lack of a more traditional assignment schedule creates some confusion with students.

Currently, the instructors consistently remind students of what assignments they should be working on and provide weekly deadlines that students should aim to meet. All assignments are also assigned in-line with what the students are learning during the lecture component, meaning that students are retroactively applying their learned knowledge to what should be the current assignment. Again, the hope is this autonomy can help students learn self-motivation and to manage their time effectively, but student participants have mentioned in the interviews that this non-traditional schedule can lead to confusion, especially with multiple instructors who may give slightly different information. An example of a participant highlighting a time of miscommunication between instructors is, "*it was literally just [Instructor 1] said, oh yeah this is due next Monday, but then [Instructor 2] goes, actually I think it's next Wednesday*," which was a memory they recounted after the experience. One recommendation to counteract this is for all instructors to have a weekly meeting to ensure that they are aware of what deadlines are coming up and what the students should be aware of for the near future. This meeting can also ensure that instructors are consistent when referring to any leniency that may exist within the schedule. If the instructors are willing to allow students to submit past deadlines or resubmit assignments, they should be consistent with what that decision is and how they communicate it to students. An online calendar is also provided to students to help organize their time, but it may be helpful to show students this schedule during class routinely to help them keep the important deadlines on their mind.

This model benefits from colleges working together. Another recommendation for any institution that wants to develop a similar model relates to the organization of a model like this. While an "innovation college," or some other separate college that can act as the home for this transdisciplinary model and employs faculty from various colleges would be ideal, institutional restrictions and coordination make it a challenging task. Currently a team of faculty from the colleges of Technology, Business Management, and Liberal Arts work together to develop the model, but to expand further would require more intentional work from all involved parties. To make it a truly transdisciplinary model, it cannot be rooted in one of these existing colleges. This can limit the engagement of students outside of the home college. Creating a separate space for this model would allow an equal opportunity for students to get involved, without any stigma based on the college that it comes from. In addition, this approach can help with the scheduling of courses with faculty across colleges as it can serve as a single coordinating unit.

5.5 Recommendations for Future Research

Engaging students in transdisciplinary work inherently requires students from varying academic backgrounds to work collaboratively. A recommendation for future research could relate to whether the skills and capabilities shown to be gained during this study are consistent across different groups of students. For this model, it has been developed based out of the Polytechnic college; therefore, there tends to be a higher percentage of technology majors present in the courses. Over the iterations, students from Liberal Arts and Business Management have grown in number, although the trend remains that technology students hold the majority. The Polytechnic college includes majors such as mechanical engineering technology, mechatronics, and electrical engineering technology, but majors such as organizational leadership, supply chain management, and engineering technology education also stem from the Polytechnic college. Beyond this inherent diversity within the Polytechnic college, there remains a gap with students learning various ethnography, customer interaction, and general business skills that students from Liberal Arts or Business Management may have the opportunity to learn. Combining these different academic backgrounds is what makes the transdisciplinary, co-learning model so effective.

Investigating whether a model developed out of a Business Management or Liberal Arts college, therefore beginning with a majority of students outside of technology majors, would have the same benefits as this study could be insightful. Theoretically, as a model nears a truly transdisciplinary environment, the skills developed should be consistent, but a lack of current research limits this knowledge at this time.

A recommendation for further research relates to the importance of the learned skills and competencies students exhibited. As mentioned earlier in the chapter, students discussed their growing confidence in various skills from this model. However, this research only aimed to identify this growth rather than detail the necessity of it. Further research could investigate the need for skills such as *integrative learning*, *problem solving*, and *teamwork*, as well as other 21st century skills that relate to innovation capabilities. While literature included in Chapter 2 discussed the general need for 21st century skills, understanding the continued need has yet to be addressed. Research could also follow students who have gone through this experience, or a similar model, and track whether their gained skills and confidence are retained over an extended period. It would be interesting to see if over time, these learned skills and capabilities remained or dwindled as they begin their professional work experiences.

Lastly, a potential drawback could be the inconsistency of the model of teaching. Inherently, each semester of the model will have a different group of students with different backgrounds. The diversity of backgrounds of students is expected to fluctuate between iterations, although the benefits of co-teaching and co-learning are expected to remain. Ensuring that the topics discussed are beneficial to all students, regardless of academic background, is crucial to enable as many students as possible to learn and grow from their experience. Also, understanding what different students coming from similar academic groups (i.e., business management students, engineering/technology students, liberal arts students, etc.) have learned prior to the course will help to tailor the learning to specific topics that they may have more or less prior knowledge in. While the course should not be changed for the sake of specific academic groups, understanding what the different thought processes students may go through when learning about a topic can help the instructors provide the best instruction to their students.

5.6 Summary

The need for innovators in the modern professional world calls for undergraduate education to rise to the challenge. While multiple strategies have been employed, a collaborative form of teaching and learning, in conjunction with an authentic, transdisciplinary learning environment, can be used to develop innovative knowledge and capabilities within students. It is important to identify effective strategies for teaching students how to be innovative, as these individuals will be called upon in the coming years to move the world forward. The data in this study seems to show that a cross-disciplinary collaborative teaching approach involving co-teaching and co-learning can assist students in developing competencies in these innovation skills. While this shift in self-efficacy may show student growth, more opportunities for research into understanding how this development enhances or impedes learning or how it will impact the workforce remains.

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APPENDIX A: INNOVATION SKILL PROMPTS

Table A.1. *Integrative Learning*

Prompt	Response Type
Synthesize connections among experiences outside of the formal classroom	Likert-scale
Deepen understanding of fields of study to broaden my own points of view	Likert-scale
Independently create a whole out of multiple parts	Likert-scale
Draw conclusions by combining examples, facts, or theories from multiple fields of study	Likert-scale
Adapt and apply skills, abilities, theories, or methods gained in one situation to new situations	Likert-scale
Solve difficult problems or explore complex issues in original ways	Likert-scale
Fulfill assignments by choosing a format, language, or graph that enhances meaning	Likert-scale
Make clear the interdependence of language and meaning, thoughts, and expression	Likert-scale
Envision a future self	Likert-scale
Make plans that build on past experiences that have occurred across multiple and diverse contexts	Likert-scale

Note: All prompts were prefaced with, "Currently, I believe I am able to:".

Table A.2. *Problem Solving*

Prompt	Response Type
Demonstrate the ability to construct a clear and insightful problem statement	Likert-scale
Identify multiple approaches for solving the problem	Likert-scale
Propose one or more solutions/hypotheses that indicates a deep comprehension of the problem	Likert-scale
Propose solutions/hypotheses that are sensitive to contextual factors	Likert-scale
Be conscious of ethical, logical, and cultural dimensions of the problem when proposing a solution	Likert-scale
Evaluate solutions deeply and elegantly	Likert-scale
Consider history of the problem, review logic/reasoning, examine feasibility of a solution, and weigh impacts of a solution	Likert-scale
Implement the solution in a way that addresses multiple contextual factors of the problem	Likert-scale
Review results thoroughly	Likert-scale
Use results to inform potential future work	Likert-scale

Note: All prompts were prefaced with, "Currently, I believe I am able to:".

Table A.3. *Teamwork*

Prompt	Response Type
Address destructive conflict directly	Likert-scale
Be helpful in managing and resolving conflict in a way that strengthens the team	Likert-scale
Treat team members with respect	Likert-scale
Convey a positive attitude about the team and its work	Likert-scale
Provide assistance and/or encouragement to the team	Likert-scale
Complete all assigned tasks thoroughly and by the deadline	Likert-scale
Be proactive with helping others complete their tasks	Likert-scale
Constructively build upon and develop the contributions of others	Likert-scale
Notice when someone is not participating and invite them to engage	Likert-scale
Help the team move forward by articulating the merits of alternative ideas	Likert-scale

Note: All prompts were prefaced with, "Currently, I believe I am able to:".

APPENDIX B: OPEN-ENDED SURVEY QUESTIONS

Table B.1. *Pre-Survey Open-Ended Questions*

Question
Describe what you are expecting from this experience.
Are you excited for this experience? Why or why not?
Explain why you chose to participate in this experience.

Table B.2. *Post-Survey Open-Ended Questions*

Question
Describe the experience
Interpret the experience: explain what this experience means to you
Evaluate the experience: appraise the quality, value, or the importance of this experience
Provide a goal statement: what will you do moving forward to continue to develop/practice these skills?

Table B.3. R*etrospective Pre-Survey Open-Ended Questions*

Question
Describe what you expected from this experience.
Were you excited for this experience? Why?
Explain why you chose to participate in this experience.

APPENDIX C: INTEGRATIVE LEARNING OUTCOMES

Table C. . *Integrative Learning – Overall Program Pre-/Post-Survey Analysis*

Sub-Construct	Mean		Z Score	P-Value	Reject/Retain
	Pre	Post			
Connections: Experience					
Synthesize connections among experiences outside of the formal classroom	4.27	4.94	-4.009	0.000	Reject
Deepen understanding of fields of study to broaden my own points of view	4.23	4.99	-3.547	0.000	Reject
Connections: Discipline					
Independently create a whole out of multiple parts	4.20	4.98	-4.493	0.000	Reject
Draw conclusions by combining examples, facts, or theories from multiple fields of study or perspectives	4.49	5.15	-4.217	0.000	Reject
Transfer					
Adapt and apply skills, abilities, theories, or methods gained in one situation to new situations	4.58	5.02	-3.920	0.000	Reject
Solve difficult problems or explore complex issues in original ways	4.27	4.98	-4.246	0.000	Reject
Integrated Communication					
Fulfill assignments by choosing a format, language, or graph that enhances meaning	4.20	4.81	-3.715	0.000	Reject
Make clear the interdependence of language and meaning, thought, and expression	4.16	4.80	-3.106	0.002	Reject
Reflection and Self-Assessment					
Envision a future self	4.68	5.11	-3.007	0.003	Reject
Make plans that build on past experiences that have occurred across multiple and diverse contexts.	4.54	5.10	-2.694	0.007	Reject

Note: n = 150

Table C.2. *Integrative Learning – Spring 2021 Retrospective Pre-/Post-Survey Analysis*

Sub-Construct	Mean		Z Score	P-Value	Reject/Retain
	Retro	Post			
Connections: Experience					
Synthesize connections among experiences outside of the formal classroom	4.43	4.93	-3.003	0.003	Reject
Deepen understanding of fields of study to broaden my own points of view	4.41	5.05	-3.425	0.001	Reject
Connections: Discipline					
Independently create a whole out of multiple parts	4.44	5.00	-2.937	0.003	Reject
Draw conclusions by combining examples, facts, or theories from multiple fields of study or perspectives	4.39	5.18	-3.661	0.000	Reject
Transfer					
Adapt and apply skills, abilities, theories, or methods gained in one situation to new situations	4.46	4.98	-2.835	0.005	Reject
Solve difficult problems or explore complex issues in original ways	4.44	4.98	-2.845	0.004	Reject
Integrated Communication					
Fulfill assignments by choosing a format, language, or graph that enhances meaning	4.22	4.82	-2.606	0.009	Reject
Make clear the interdependence of language and meaning, thought, and expression	4.31	4.85	-2.706	0.007	Reject
Reflection and Self-Assessment					
Envision a future self	4.35	5.13	-3.879	0.000	Reject
Make plans that build on past experiences that have occurred across multiple and diverse contexts.	4.43	5.18	-4.126	0.000	Reject

Note: n = 54

Table C.3. *Integrative Learning – Fall 2021 Pre-/Post-Survey Analysis*

Sub-Construct	Mean		Z Score	P-Value	Reject/Retain
	Pre	Post			
Connections: Experience					
Synthesize connections among experiences outside of the formal classroom	4.24	5.02	-4.090	0.000	Reject
Deepen understanding of fields of study to broaden my own points of view	4.22	5.02	-3.344	0.001	Reject
Connections: Discipline					
Independently create a whole out of multiple parts	4.27	5.02	-3.952	0.000	Reject
Draw conclusions by combining examples, facts, or theories from multiple fields of study or perspectives	4.54	5.14	-3.643	0.000	Reject
Transfer					
Adapt and apply skills, abilities, theories, or methods gained in one situation to new situations	4.69	5.08	-2.997	0.003	Reject
Solve difficult problems or explore complex issues in original ways	4.31	5.02	-3.695	0.000	Reject
Integrated Communication					
Fulfill assignments by choosing a format, language, or graph that enhances meaning	4.32	4.92	-3.200	0.001	Reject
Make clear the interdependence of language and meaning, thought, and expression	4.22	4.84	-2.974	0.003	Reject
Reflection and Self-Assessment					
Envision a future self	4.86	5.14	-2.182	0.029	Reject
Make plans that build on past experiences that have occurred across multiple and diverse contexts.	4.58	5.06	-2.461	0.014	Reject

Note: n = 72

APPENDIX D: PROBLEM SOLVING OUTCOMES

Table D.1. *Problem Solving – Overall Model Pre-/Post-Survey Analysis*

Sub-Construct	Mean		Z Score	P-Value	Reject/Retain
	Pre	Post			
Define Problem					
Demonstrate the ability to construct a clear and insightful problem statement	4.47	4.94	-3.387	0.001	Reject
Identify Strategies					
Identify multiple approaches for solving the problem	4.61	5.21	-4.151	0.000	Reject
Propose Solutions/Hypotheses					
Propose one or more solutions/hypotheses that indicates a deep comprehension of the problem	4.27	5.11	-4.546	0.000	Reject
Propose solutions/hypotheses that are sensitive to contextual factors	4.28	5.05	-3.931	0.000	Reject
Be conscious of ethical, logical, and cultural dimensions of the problem when proposing a solution	4.53	5.02	-3.122	0.002	Reject
Evaluate Solutions					
Evaluate solutions deeply and elegantly	4.32	5.02	-3.235	0.001	Reject
Consider history of the problem, review logic/reasoning, examine feasibility of a solution, and weigh impacts of a solution	4.24	4.98	-4.376	0.000	Reject
Implement Solutions					
Implement the solution in a way that addresses multiple contextual factors of the problem	4.20	5.00	-3.787	0.000	Reject
Evaluate Outcomes					
Review results thoroughly	4.47	5.00	-3.294	0.001	Reject
Use results to inform potential future work	4.57	5.17	-3.141	0.002	Reject

Note: n = 150

Table D.2. *Problem Solving – Spring 2021 Retrospective Pre-/Post-Survey Analysis*

Sub-Construct	Mean Retro	Mean Post	Z Score	P-Value	Reject/Retain
Define Problem					
Demonstrate the ability to construct a clear and insightful problem statement	4.40	4.87	-3.679	0.000	Reject
Identify Strategies					
Identify multiple approaches for solving the problem	4.80	5.13	-2.604	0.009	Reject
Propose Solutions/Hypotheses					
Propose one or more solutions/hypotheses that indicates a deep comprehension of the problem	4.57	5.05	-2.976	0.003	Reject
Propose solutions/hypotheses that are sensitive to contextual factors	4.50	5.30	-3.607	0.000	Reject
Be conscious of ethical, logical, and cultural dimensions of the problem when proposing a solution	4.60	5.05	-3.155	0.002	Reject
Evaluate Solutions					
Evaluate solutions deeply and elegantly	4.55	5.10	-3.988	0.000	Reject
Consider history of the problem, review logic/reasoning, examine feasibility of a solution, and weigh impacts of a solution	4.48	4.88	-2.549	0.011	Reject
Implement Solutions					
Implement the solution in a way that addresses multiple contextual factors of the problem	4.55	4.93	-2.421	0.015	Reject
Evaluate Outcomes					
Review results thoroughly	4.55	4.98	-2.863	0.004	Reject
Use results to inform potential future work	4.78	5.17	-2.408	0.016	Reject

Note: n = 54

Table D.3. *Problem Solving – Fall 2021 Pre-/Post-Survey Analysis*

Sub-Construct	Mean		Z Score	P-Value	Reject/Retain
	Pre	Post			
Define Problem					
Demonstrate the ability to construct a clear and insightful problem statement	4.44	5.08	-3.435	0.001	Reject
Identify Strategies					
Identify multiple approaches for solving the problem	4.64	5.25	-3.531	0.000	Reject
Propose Solutions/Hypotheses					
Propose one or more solutions/hypotheses that indicates a deep comprehension of the problem	4.34	5.16	-3.863	0.000	Reject
Propose solutions/hypotheses that are sensitive to contextual factors	4.31	5.06	-3.337	0.001	Reject
Be conscious of ethical, logical, and cultural dimensions of the problem when proposing a solution	4.56	5.02	-2.852	0.004	Reject
Evaluate Solutions					
Evaluate solutions deeply and elegantly	4.31	4.88	-2.755	0.006	Reject
Consider history of the problem, review logic/reasoning, examine feasibility of a solution, and weigh impacts of a solution	4.31	5.08	-3.740	0.000	Reject
Implement Solutions					
Implement the solution in a way that addresses multiple contextual factors of the problem	4.31	5.06	-2.881	0.004	Reject
Evaluate Outcomes					
Review results thoroughly	4.59	5.06	-2.922	0.003	Reject
Use results to inform potential future work	4.64	5.14	-2.396	0.017	Reject

Note: n = 72

APPENDIX E: TEAMWORK OUTCOMES

Table E.1. *Teamwork – Overall Model Pre-/Post-Survey Analysis*

Sub-Construct	Mean		Z Score	P-value	Reject/Retain
	Pre	Post			
Response to Conflict					
Address destructive conflict directly	4.16	4.75	-1.980	0.048	Reject
Be helpful in managing and resolving conflict in a way that strengthens the team	4.61	4.88	-1.912	0.056	Retain
Constructive Team Climate					
Treat team members with respect	5.42	5.39	-0.507	0.612	Retain
Convey a positive attitude about the team and its work	5.12	5.33	-0.441	0.660	Retain
Provide assistance and/or encouragement to the team	5.12	5.34	-1.837	0.066	Retain
Individual Contributions					
Complete all assigned tasks thoroughly and by the deadline	5.19	5.03	-0.683	0.494	Retain
Be proactive with helping others complete their tasks	4.89	5.14	-0.685	0.494	Retain
Facilitating Team Member Contributions					
Constructively build upon and develop the contributions of others	4.95	5.22	-1.218	0.223	Retain
Notice when someone is not participating and invite them to engage	4.55	4.97	-0.623	0.533	Retain
Contributing to Team Meetings					
Help the team move forward by articulating the merits of alternative ideas	4.88	5.15	-1.428	0.153	Retain

Note: n = 150

Table E.2. *Teamwork – Spring 2021 Retrospective Pre-/Post-Survey Analysis*

Sub-Construct	Mean		Z Score	P-value	Reject/Retain
	Retro	Post			
Response to Conflict					
Address destructive conflict directly	4.28	4.78	-2.557	0.011	Reject
Be helpful in managing and resolving conflict in a way that strengthens the team	4.57	4.85	-1.992	0.046	Reject
Constructive Team Climate					
Treat team members with respect	5.08	5.38	-2.576	0.010	Reject
Convey a positive attitude about the team and its work	4.98	5.37	-3.019	0.003	Reject
Provide assistance and/or encouragement to the team	4.90	5.35	-3.567	0.000	Reject
Individual Contributions					
Complete all assigned tasks thoroughly and by the deadline	4.87	5.10	-1.748	0.080	Retain
Be proactive with helping others complete their tasks	4.72	5.23	-3.437	0.001	Reject
Facilitating Team Member Contributions					
Constructively build upon and develop the contributions of others	4.85	5.32	-3.375	0.001	Reject
Notice when someone is not participating and invite them to engage	4.53	5.08	-3.478	0.001	Reject
Contributing to Team Meetings					
Help the team move forward by articulating the merits of alternative ideas	4.80	5.15	-2.713	0.007	Reject

Note: n = 54

TableE.3. *Teamwork – Fall 2021 Pre-/Post-Survey Analysis*

Sub-Construct	Mean		Z Score	P-value	Reject/Retain
	Pre	Post			
Response to Conflict					
Address destructive conflict directly	4.24	4.82	-1.600	0.110	Retain
Be helpful in managing and resolving conflict in a way that strengthens the team	4.73	4.96	-1.462	0.144	Retain
Constructive Team Climate					
Treat team members with respect	5.49	5.43	-0.175	0.861	Retain
Convey a positive attitude about the team and its work	5.14	5.31	-0.660	0.509	Retain
Provide assistance and/or encouragement to the team	5.20	5.35	-1.407	0.159	Retain
Individual Contributions					
Complete all assigned tasks thoroughly and by the deadline	5.25	5.10	-0.436	0.663	Retain
Be proactive with helping others complete their tasks	4.93	5.12	-0.941	0.347	Retain
Facilitating Team Member Contributions					
Constructively build upon and develop the contributions of others	5.02	5.18	-1.306	0.192	Retain
Notice when someone is not participating and invite them to engage	4.58	4.96	-0.630	0.529	Retain
Contributing to Team Meetings					
Help the team move forward by articulating the merits of alternative ideas	4.97	5.16	-0.947	0.343	Retain

Note: $n = 72$