University of Louisville
ThinkIR: The University of Louisville's Institutional Repository

Electronic Theses and Dissertations

8-2021

Engineering performance and teamwork perceptions shaped by structured learning experiences in a makerspace.

Teresa Lee Tinnell
University of Louisville

Follow this and additional works at: https://ir.library.louisville.edu/etd

Part of the Curriculum and Instruction Commons, Educational Methods Commons, Educational Technology Commons, and the Science and Mathematics Education Commons

Recommended Citation

Tinnell, Teresa Lee, "Engineering performance and teamwork perceptions shaped by structured learning experiences in a makerspace." (2021). *Electronic Theses and Dissertations.* Paper 3691.
Retrieved from https://ir.library.louisville.edu/etd/3691

This Doctoral Dissertation is brought to you for free and open access by ThinkIR: The University of Louisville's Institutional Repository. It has been accepted for inclusion in Electronic Theses and Dissertations by an authorized administrator of ThinkIR: The University of Louisville's Institutional Repository. This title appears here courtesy of the author, who has retained all other copyrights. For more information, please contact thinkir@louisville.edu.

ENGINEERING PERFORMANCE AND TEAMWORK PERCEPTIONS SHAPED BY STRUCTURED LEARNING EXPERIENCES IN A MAKERSPACE

By

Teresa Lee Tinnell
B.A., University of Louisville, 2008
M.A.T., University of Louisville, 2010

A Dissertation
Submitted to the Faculty of the
College of Education and Human Development of the University of Louisville
in Fulfillment of the Requirements
for the Degree of

Doctor of Philosophy
in Curriculum and Instruction

Department of Elementary, Middle and Secondary Teacher Education
University of Louisville
Louisville, KY

August 2021

Copyright © 2021 by Teresa L. Tinnell

All rights reserved

ENGINEERING PERFORMANCE AND TEAMWORK PERCEPTIONS SHAPED BY STRUCTURED LEARNING EXPERIENCES IN A MAKERSPACE

By

Teresa L. Tinnell
B.A., University of Louisville, 2008
M.A., University of Louisville, 2010

A Dissertation Approved on

July 13, 2021

by the following Dissertation Committee:

Dissertation Director
Dr. Thomas R. Tretter

Dr. Stephanie B. Philipp

Dr. Patricia S. Ralston

Dr. Justin R. McFadden

Dr. Sheron L. Mark

DEDICATION

This dissertation is dedicated to my husband, Chad, my teammate for life.

This dream was achievable with your support and persistent belief in me.

What a mighty and loving God we serve that he would join us together for this sweet life.

To our sweetest blessing, Raegan, I devote all my talents to your future.

May you always know just how special you are and follow the light that shines in your heart, it is a bright one sweet girl.

ACKNOWLEDGMENTS

This dissertation would not have been possible without the mindful advice, guidance, and thorough feedback of my mentor Dr. Tom Tretter. I am grateful for each thoughtful task, assignment, and pondering point offered that carried me through this journey of thought which I could have never imagined from the beginning. I am thankful for your professionalism, leadership, and genuine care of your student's well-being.

I owe tremendous thanks to Dr. Brian Robinson. His openness, willingness, and authentic excitement for continual learning is what made this dissertation what it is. Dr. Robinson was ever on the ready with assistance by offering pedagogical insights and experiential wisdom. You are the ideal collaborator and all-around amazing human.

My doctoral journey was supremely blessed by the amazing mentorship and friendship of Dr. Patricia Ralston. Words simply do not do justice to the amount of thanks I owe Dr. Ralston for all the ways she has supported my process. Dr. Ralston has been a consistent champion of my work, encouraging me to find my own voice in the research and advocating for recognition of its value. Thank you, Dr. Ralston, for believing in me and investing so much of yourself into my future.

To my dissertation committee, thank you for the continuous opportunities of learning with enduring support throughout this entire journey. I developed a sense of confidence in myself and my words with Dr. Stephanie Philipp's wise advice to believe in my instincts. I found new understandings of myself and my worldview through the many heartfelt conversations with Dr. Sheron Mark. And the experiences Dr. Justin

McFadden provided brought me a newfound approach to research that has expanded opportunities leading to deeper understandings. I am especially thankful for all the professional collegiality afforded to me by my committee. I will carry your examples of positive role modeling and relationship building as I continue this journey.

I am and will remain eternally grateful to my parents, Mark and Janice Henry. Dad, you have always believed in me and made sure that I always knew my worth. Your devotion to me and our family has instilled a bond of love that continues, now extending to your granddaughter. You are and always have been the best. Mom, you are my best friend. You stand beside me in any situation, champion my decisions, and ensure happiness everywhere you go. I am thankful God chose you as my earthly guardians.

Throughout this doctoral journey there have been many personal supports. Of particular importance I am so thankful for the encouragement and consistent reassurance offered by my officemate, Dr. Campbell Bego. I also owe a special thanks to the future Dr. Jody Zhong, my second officemate, and special independent coder; thank you for your ever ready assistance and persistent optimism.

Lastly, I thank all those family and friends that offered kind comments, childcare assistance, and offerings of coffee. My sisters, Amanda and Katie Henry consistently provided energy and relaxation outlets that always uplifted your niece with a full and happy heart. And to my father- and mother-in-law, Paul & Barbara Tinnell, thank you for your never ceasing commitment to family and our little girl. We are a blessed family.

ABSTRACT

ENGINEERING PERFORMANCE AND TEAMWORK PERCEPTIONS SHAPED BY STRUCTURED LEARNING EXPERIENCES IN A MAKERSPACE

Teresa L. Tinnell

July 13, 2021

The ability to work on teams is of critical importance to the field of engineering and a critical competency for future engineers. Fostering performance of effective teamwork through the education of engineers emphasizes the humanistic dimension of the engineering profession and engages future engineering professionals in complex and dynamic team experiences. Team performance and effectiveness of student teams is strongly influenced by individual student perceptions of teamwork as a learning mechanism for successful collective learning experiences. Initial perceptions of teamwork among first year engineering students are often negative due to prior adverse or unproductive team performance. Makerspace learning environments are becoming more prominent in engineering education as promising environments for open-ended, team-based learning experiences that promote positive perceptions of teamwork and performance. The educational potential that makerspaces have to promote engineering design-thinking among the community of teams has great appeal among engineering education.

This study explored the engineering performance and student teamwork perceptions of a cohort of first year engineering students (*N=488, 126 teams*) engaged in a team-based learning experience within a makerspace learning environment. The mixed methods convergent case study design examined teams within and across cases to extract systematic patterns within and across the three constructs of this study: 1) team effectiveness, 2) engineering practice, and 3) teamwork perceptions. Using a 3-phase analysis approach teams were found to be effective in their ability to perform and a relationship emerged between the effectiveness of a team and the team's collective efficacy. Student perceptions were found to shift over time and through experience. The team-based learning experience implemented through the course was valuable to improving student perceptions of teamwork by 1) ensuring multidisciplinary teams, 2) gradually releasing teams to perform complex, ill-structured problem solving, and 3) using the resources and space within the makerspace to encourage teams to creatively solve the design problem. More research is needed to investigate the inner dynamics of the teams, particularly how well makerspace learning environments engage diverse individuals and what differences exist among experiences.

Keywords: *teamwork, engineering practice, team effectiveness, makerspace learning, team-based learning, engineering education*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I: INTRODUCTION

The ability to work on a team as a critical competence is prominent in engineering education (Lingard, 2010; Passow & Passow, 2017). This is evidenced by the multiple student outcomes the Accreditation Board for Engineering and Technology (ABET) has in place that emphasizes students' professional ability to effectively function on a team (ABET, 2021). To address this competency, engineering education has incorporated team-based learning (TBL) as a way to instill fundamental engineering concepts (Najdanovic-Visak, 2017) and set up an appropriate framework for problem- and project-based engineering education (Mills & Treagust, 2003; Prince & Felder, 2006) that ensures engineering graduates are competent, design-thinking professionals (Dym, Agogino, Eris, Frey, & Leifer, 2005). This emphasis on the humanistic dimension of the engineering profession involves fostering the ability of future engineers to perform effectively on teams, which are characteristically complex and dynamic systems (Kozlowski & Ilgen, 2007; Mathieu, Maynard, Rapp, & Gilson, 2008).

The practice of engineering, particularly design engineering, relies on the impromptu negotiations, discussions, and levity among team members. Historically, however, team- and problem-based activity are rarely utilized in the predominantly lecture-based and deductive-dominant engineering classes that comprise an engineering degree program (Kerr, 2015; Sheppard, Macatangay, Colby, & Sullivan, 2009). These traditional, lecture-based classrooms promote few characteristics that generate creative processes and even fewer opportunities for collaboration of intellectual exploration and teamwork that is vital to producing elegant final-design products that demonstrate effective team performance (Goldman, Kabayadondo, Royalty, Carroll, & Roth, 2014). Additionally, these traditional classrooms do little to promote positive perceptions of teamwork among engineering students (Alves, Mesquita, Moreira, & Fernandes, 2012; Garmendia Mujika, Garikano Osinaga, Sierra Uria, & Perez Manso, 2013). The performance and effectiveness of student teams is strongly influenced by individual student's initial perception toward the use of team as a mechanism for a successful collective learning experience (Lent, Schmidt, & Schmidt, 2006). The initial perception of teamwork among many first-year engineering students is often negative due to prior adverse team experiences or dysfunctional team performance (Adams, Turns, & Atman, 2003; Lingard, 2010). When engineering educators support student's development of effective team processes the student's positive perception of working in teams increases (Oakley, Hanna, Kuzmyn, & Felder, 2007). Engineering coursework with team-based projects is an approach to minimize the 'lone wolf' tendency of engineering students preferring or choosing not to engage with the team's process of work (Barr, Dixon, & Gassenheimer, 2005).

Makerspaces present promising sites for open-ended, team-based learning experiences (Sheridan et al., 2014; Vossoughi & Bevan, 2014), beneficial to the promotion of positive perceptions of teamwork and performance (Richard & Giri, 2017). The concept of a makerspace has evolved over time and is broadly understood to be a space for people to practice the iterative process of making, which means to tinker or fabricate. In general, makerspaces are environments where individuals manipulate resources, high-tech or low-tech, to create items that represent their ideas. The educational potential of makerspaces has been highlighted in a variety of venues, including: schools and libraries (Bevan, Gutwill, Petrich, & Wilkinson, 2015), educational research (Halverson & Sheridan, 2014; Peppler & Bender, 2013), and community spaces (Calabrese Barton & Tan, 2018; Giannakos, Divitini, Iversen, & Koulouris, 2015). Additionally, makerspaces have innate features that promote use of design-thinking among teams of designers (Giannakos, Divitini, & Iversen, 2017); an appealing characteristic for engineering education advocates (Newstetter & Svinicki, 2015).

Makerspaces have grown in popularity as many engineering education programs are funding the creation of makerspace learning environments with the intent that department faculty use the environments to better facilitate engineering students' skill development in teamwork. Competencies relevant to the professional practice of engineering are intertwined with teamwork effectiveness, identifiable through the successful performance of collaboration, communication, creative problem solving (Passow & Passow, 2017). From the beginning, makerspaces have maintained design features that are informal in learning structure and community-based in their use. These innate features of the first makerspaces are what sparked the excitement of learning through making and the engagement of team-based, community design (Sheridan et al., 2014; Vossoughi & Bevan, 2014).

The use of makerspaces as formal, structured learning environments is a more recent educational phenomenon, one that has the attention of engineering educators as the potential intersections of engineering practice competencies intertwined with authentic student engagement (Barton, Tan, & Greenberg, 2016; Saorín et al., 2017). While engineering educators identify the learning benefits of makerspaces (Hira, Joslyn, & Hynes, 2015), the understanding of how effective makerspace learning environments are contributing to student teamwork performance and improving teamwork perceptions is understudied, yet needed as engineering programs increase utilization of makerspace learning environments.

Study Background

In the Fall of 2014, the Dean of the J.B. Speed School of Engineering at the University of Louisville initiated a charge for a core cadre of engineering leadership and faculty to contribute to a curriculum revision that would ultimately result in a redesign of how engineering students are introduced to the profession of engineering by way of establishing a common first-year experience for all students. The initial curriculum revision committee was comprised of a representative from each engineering department, administrators from the engineering school's academic affairs office, and a committee chair. The committee chair also served as department chair of the engineering department slated to implement the coursework resulting from the curriculum redesign. The committee examined engineering programs and visited similar engineering schools identified as having a common first-year experience. That exploration of common first-year experiences resulted in the committee identifying essential competencies necessary for student success in engineering, and at the core of the engineering competencies was the indispensable need of explicit pedagogy leading to student skill development in teamwork.

Among the coursework recommendations was the call for the school of engineering to implement a two-semester sequence of courses that would provide an introduction to engineering practice and experience with essential engineering methods, tools, and practice for all first-year students. The first course of the sequence, referred to as engineering methods, was described as a *skills development* and active learning course. The second course of the sequence, referred to as the engineering design course, required a demonstration of *skill acquisition and integration* by the demonstration of a team design project, referred to as the cornerstone design project. A key learning outcome of the engineering design course was for student design teams to demonstrate effective teamwork through their performance of engineering practice.

The cornerstone design project for the engineering design course consisted of each student design team successfully constructing an efficiently functioning model windmill. The efficiency and functionality of the windmills was dependent on each student design team's collective execution of three main tasks: 1) generating 3-dimensional printed parts that provides function to the windmill, 2) programming a microcontroller that provides efficiency readings from the windmill power generation, and 3) composing a written technical report detailing the team's design process and final results. For each of these tasks to be executed successfully by the end of the semester, student design teams needed to exemplify team effectiveness through clear communication, collaboration, and creative problem solving. The university used the newly created academic makerspace as the classroom learning environment to provide support to the development of student teamwork effectiveness.

Study Purpose

Designing is a key competency of engineering practice. Engagement in design requires engineers to integrate knowledge, skill, and forethought in the pursuit of creatively and collaboratively solving the problems that plague daily life. When the design process takes place within a makerspace environment, the value of innovative ideas and creative problem solving is enhanced. In the makerspace learning environment of this study, design serves as a mechanism that naturally engages individuals to collaborate on design teams that coalesce around a common design project. This study's engineering design course, conducted within a makerspace learning environment, engages student design teams in the practice of engineering through the demonstration of effective teamwork performance and advancement of student perceptions of effective teamwork.

The curriculum of the engineering design course was intentionally crafted with a structure intended to encourage engineering students to explore ideas of solving ill-structured, 'wicked' design problems (Rittel & Webber, 1973). The learning environment of the makerspace encourages student persistence to develop successful design solutions; achieving success through performance could bolster student perceptions of teamwork. The formation of student design teams follows the TBL framework (Michaelsen & Sweet, 2008), as each design team is intentionally formed with students of differing engineering-major and students of non-majority race and/or gender are teamed together. Additionally, design team members were routinely required to provide feedback of team effectiveness to teammates, and the graduate teaching assistants (GTA) consistently provided teams feedback on engineering performance and team effectiveness.

The engineering design course was comprised of six separate classes, held on different days of the week and at different times each day. This study focuses on features of the individuals (students) and the teams that comprise each engineering design class. Data collected for this study include quantitative (e.g., cornerstone project design scores, GTA team effectiveness ratings, peer evaluations of team member effectiveness, and teamwork perception survey results) and qualitative GTA team effectiveness comments (per team). The specific purpose of this study is to explore how effective a makerspace learning environment is in promoting team performance through team effectiveness and engineering practice. Since student perceptions of teamwork cannot be disentangled from a team's ability to perform effectively, this study also investigates the gains a TBL experience encourages in students' teamwork perceptions.

Study Significance

This study will contribute to new understandings of a TBL experience on first-year engineering students' teamwork perceptions and performance of engineering practices and effective teamwork. The context of this study, within an academic makerspace environment, presents a unique learning environment with innate features that encourage and bolster the value of teamwork among students. Considering the importance of effective teamwork skills for engineers as articulated by the profession, as well as employers, there may be promise in this structured approach for first-year engineering students to deepen their acquisition of this important skill set.

Research Questions

Grounded in the theoretical and conceptual frameworks described in chapter two, the following research questions were posed to explore performance and perceptions of teamwork among first-year engineering students, engaged in a team-based learning design experience in a makerspace:

1. Is a makerspace learning environment effective for promoting student design teams' engineering **performance** in…
    a. Team effectiveness?
    b. Engineering practice?
2. To what extent does the team-based learning experience in a makerspace promote positive gains in students' teamwork **perceptions**?

CHAPTER II: REVIEW OF THE LITERATURE

This chapter consists of three main sections that summarize the empirical and theoretical scholarship regarding the effectiveness of makerspace environments and team-based learning (TBL) in promoting engineering performance and perceptions. The first section describes the makerspace environment as a situated learning space with inherent qualities that encourage engineering design thinking and value effective teamwork. The second section depicts the pedagogical approaches of the engineering design course and the intended learning experience outcomes of student performance and perception. The third section provides the theoretical framework that guides the formation of the conceptual framing for this study.

Learning Situated in a Makerspace Environment

Makerspaces are usually informal sites intended for creative production of art, science, and engineering where people blend digital and physical technologies to explore ideas, learn technical skills, and create new products (Sheridan et al., 2014). Originally informal in nature, makerspaces are a key component of a larger maker movement comprised of individual makers, local and regional maker events, and a cornucopia of digital do-it-yourself resources (Dougherty, 2012). Makerspaces are comprised of participants varying in age and levels of expertise; however, commonalities include engagement and learning of all participants focused on a common product. The learning environment and structure of a makerspace situate individuals to collaborate, communicate, critically think, and contribute to an overarching project; relying on the resources, shared knowledge, and expertise of those involved in the task at hand. This type of community skill building, bringing together diverse individuals, disciplines, and activities gives rise to the potential opportunities for learning that is important for the development of emerging engineers (Choi, Bouwma-Gearhart, Lenhart, Villanueva, & Nadelson, 2021).

The maker movement is gaining in credibility as an innovative way to reimagine education and learning (Halverson & Sheridan, 2014; Martin, 2015; Peppler & Bender, 2013) during a time of persistent inequities among science, technology, engineering, and mathematics (STEM) education and career pathways (National Science Foundation, 2018). The movement has created a culture of people who make connections and find ways to express themselves through making, thus sparking an explosion of makerspaces throughout the United States. “Tens of thousands of kids, adults, and families are drawn to the exciting new technologies, expert marketing, and strong word of mouth that characterize this movement” (Halverson & Sheridan, 2014, p. 495). The culture of makerspaces emphasizes learning by doing, construction, and innovation; all key features of engineering education (Saorín et al., 2017).

This model of learning through doing is not new to education (e.g. Dewey, 1938; Papert,1975), however, the maker movement appears to possess great promise among education outlets in appealing to student’s need to engage passionately with learning objectives that require them to participate inquisitively, as more than passive consumers (Halverson & Sheridan, 2014). Participating in making incorporated the language and cultural tools Vygotsky (1978) described in helping shape thinking and higher cognitive understanding. Students collaboratively and critically engaging in solving complex problems via application of appropriate knowledge and analytical processes are consistent with the development of teamwork and engineering practices that are strongly desired of future engineers (ABET, 2021).

Engineering Design Thinking in a Makerspace

Design has been widely considered to be a central or distinguishing activity of engineering (Simon, 1996). Like problem solving, design is a natural and omnipresent human activity that often taps into expressions of practical ingenuity, a desired attribute of innovative engineers (Veenstra, Dey, & Herrin, 2009). The start to any design process stems from the ambition to act on needs and dissatisfaction with a current state. It has been said that engineering programs should graduate engineers who can design effective solutions to meet social needs (Evans, Beakley, Crouch, & Yamaguchi, 1993; Sheppard, 2003). Success in today’s highly technical and globally competitive world requires a different set of skills than have ever been needed before (de Figueiredo, 2013), among these skills is the utilization of explicit problem decomposing strategies (Cross, 2001). In engineering, expert designers are often identified by their use of integrated design strategies, versus trial-and-error techniques commonly used by novices (Razzouk & Shute, 2012). The progression from novice to expert is refined through experience and engagement within the environment and with the available resources and tools.

Through engagement with engineering design thinking, the inherent features of makerspaces lend themselves to positive student experiences with teamwork (Giannakos et al., 2015) and engage students with the practices of engineering (Saorín et al., 2017). Because experiences gained within the makerspace involve students in problem-solving, self-direction, and collaborative teamwork (Halverson & Sheridan, 2014), these experiences and practices strongly align with engineering education goals (Vossoughi & Bevan, 2014).

Makerspaces Supporting Teamwork in Engineering

Learning to work and perform in teams is essential for engineering graduates entering the work force. The ability to work on a team, effectively and efficiently to achieve a common set of goals requires a special skillset that is of high value to the profession of engineering (ABET, 2021; Passow & Passow, 2017). Several education initiatives, such as project-based learning and team-based learning, have been used to promote teamwork skills (Johnson & Ulseth, 2017; Michaelsen, Davidson, & Major, 2014; B. Oakley, Felder, Brent, & Elhajj, 2004). However, in engineering classrooms, teamwork remains seen by most of the engineering students as a course requirement to get a grade, rather than a skill they need to master to become effective engineers. A part of the problem is that students are selected and assigned to teams with the expectation that they will know how to effectively work with other without receiving any teamwork training. Gallegos (2011) argued that simply placing students into groups does not automatically develop teamwork skills. It is also common among first-year engineering students to have an initial, negative perception of teamwork due to prior adverse team experiences or dysfunctional team performance (Adams & Laksumanage, 2003; Lingard, 2010).

Makerspaces possess unique characteristics as a learning environment that have not only have been shown to enhance engineering students' undergraduate experience (Saorín et al., 2017; Wilczynski & Adrezin, 2016), they are also attributed to providing support that fosters positive peer-to-peer interactions and activity, promoting the use of effective teamwork and skills (Choi et al., 2021; Yu, 2016). The learning environment and structure of a makerspace situates students to collaborate, communicate, critically think, and contribute to an overarching project that approaches a complex, ill-structured problem (Ge & Land, 2003). This type of community skill building, bringing together diverse individuals, disciplines, and activities; gives rise to the potential opportunities for learning that is important for the development of emerging engineers (Choi et al., 2021).

It should be said that while makerspaces have been credited in affording numerous positive student learning outcomes, some studies show they do not live up to the grand potential expressed in so many educational makerspace investigations (Vossoughi, Hooper, & Escudé, 2016). Skepticism of makerspace, specifically those used for the purposes of education and learning, have two threads of importance to this study. The first thread stems from faculty members expressed concern that students may develop incomplete or inaccurate notions of engineering through makerspace activities, conceptualizing engineering practice as primarily consisting of rapid prototyping and advanced technology or tool use (Lenhart, Bouwma-Gearhart, Villanueva, Youmans, & Nadelson, 2020).

The second thread takes an appropriately critical consideration of some of the most acclaimed design benefits of a makerspace. Makerspaces (community-based or academic) are typically designed for the purposes of bringing diverse users, activities, and communities together; often, explicitly described as places that enable and encourage interdisciplinary and cross-sectional work (Sheridan et al., 2014; Yu, 2016). However, the question remains whether the intended outcomes of makerspace (especially those intended for academic and educational purposes) uphold in practice and whether users of makerspaces perceive the potential learning opportunities as beneficial and inclusive.

This study explores the effectiveness of an academic makerspace learning environment in the promotion of student design teams' performance through team effectiveness, and the demonstration as a team of engineering practice, while capturing the extent to which the team-based learning experience promotes positive gains in student teamwork perceptions.

Engineering Design Course Pedagogy

The pedagogical approach of the engineering design course at the heart of this study models the framework of team-based learning (TBL). TBL is an innovative and effective approach to engineering education involving cooperative interaction among small groups of students to achieve a common set of goals. When implemented effectively, it helps students enhance social and intellectual aptitudes in a curriculum environment (Knight, Carlson, & Sullivan, 2003; Michaelsen, Knight, & Fink, 2002). Specific to engineering education, TBL has been shown to enhance the learning experience for students (Lamm, Dorneich, & Rover, 2014; Najdanovic-Visak, 2017; Passow & Passow, 2017). Effective team development requires adequate time for students to settle into their team and develop the cohesiveness necessary to share responsibility of the work involved. With most teams in an academic setting being formed by the instructor, a critical part of their development is relieving prior conflict among team members (Michaelsen et al., 2002).

TBL framework has been found to support the development of high functioning, cohesive team dynamics where teams do not depend on the strongest or smartest individuals, but rather embrace talents of all their members (Kasl, Marsick, & Dechant, 1997; Mott & Peuker, 2015). TBL consists of four essential elements (Michaelsen & Sweet, 2008): 1) properly formed and managed teams; 2) student accountability for the quality of both individual and team's work; 3) timely and frequent feedback from the instructor; and 4) design of team assignments that promote learning and team development. The engineering design course reflects these elements, as: 1) teams are intentionally formed with members of varying discipline-specified engineering majors, 2) faculty and students utilize online software that maintains accountability for specific individual and team assignments, and 3) feedback is an expected and executed instructional strategy utilized by faculty in all forms of assessment (i.e., in-person or online/written). Additionally, multiple faculty and graduate teaching assistants are assigned to each class of the engineering design course, resulting in the promotion of learning and team development through consistent and fluid communication from instructors-to-students, student-to-instructors, and students-to-students.

For self-managing TBL groups, two conditions are essential (Michaelsen et al., 2014): 1) the groups must have the freedom to manage their own interaction, and 2) every activity and assignment must be explicitly designed and managed to provide immediate performance feedback. A fixed component of the engineering design course is the peer-evaluations, collected at three time-points during the semester. The peer-evaluations are completed by each student and used to hold students accountable for individual performance and contribution to the team, to give constructive feedback to individual students, and to manage team conflict.

Ill-structured Problem Solving

An instructional approach that has been shown to encourage the essential elements of TBL is the implementation of ill-structured problems (Jonassen, 1997; Lönngren, 2017). Ill-structured problems are situated in and emergent from a specific context; typically situated in such a way that one or more aspects of the problem are not well specified (Ge & Land, 2003). Ill-structured problems are cited as similar to that of an engineering workplace, both complex and ill-defined (Jonassen, Strobel, & Lee, 2006). Engineering courses focused on design, especially those created for first-year engineering students, are seeing success in student motivation by approaching problem-solving in a scaffolded manner and gradually releasing to ill-structure problems with greater complexity (Ge & Land, 2003).

This study's engineering design course retains a gradual-release structure in which the semester begins with an abundance of resource opportunities provided to students. Resource opportunities, such as online guided videos for each class meeting, detailed class procedures (printed and available online), and frequent in-class and online reminders of class activity sent to students. The middle of the semester marks the point in which these resources, class procedures, and reminders are tapered and the expectation of responsibilities to maintain course requirements, activities, and communication shifts from instructors to students and the student teams. Similar to an engineering workplace, the success of student teams is dependent on their effectiveness as a team to efficiently communicate, collaborate, and problem-solve in a timely manner. For the student teams of the engineering design course to successfully fulfill the design requirements and solve the ill-structured design problem, it is essential that the teams collectively perform as an effective design team.

Team Effectiveness

Team effectiveness is defined as the degree to which a team's output meets requirements of performance (i.e. quality of physical artifact, written documentation, and the oral presentation) through the process of team functioning and cognition (i.e. shared understanding of task and team member attributes) (Borrego, Karlin, McNair, & Beddoes, 2013; Hackman, 1990; Mathieu et al., 2008). Team cognition refers to the cognitive structures or knowledge representations that help members of a team efficiently and effectively organize and execute tasks toward achieving the team's goal (Kozlowski & Ilgen, 2007). Team cognition has two facets of impact on team effectiveness. The first is the mental representations that team members hold about themselves and the task; the second is the mental representations of the awareness of others' knowledge in the group (DeChurch & Mesmer-Magnus, 2010). Team cognition is described as a bottom-up emergent state that originates in individuals and emerges as a pattern at the team level (Kozlowski & Bell, 2008). Team effectiveness encompasses the process of team functioning and is directly observable in the team's efficient completion of an end goal.

In a study to better understand team effectiveness, Adams et al. (2002) identified seven characteristics necessary within the process of teamwork in order for a team to be effective. These characteristics are productive conflict resolution, mature communication, role clarity, accountable interdependence, goal clarification, common purpose, and psychological safety.

Productive conflict resolution refers to the process and actions taken during a conflict situation that leads to outcomes like: facilitating the solution to a problem, increasing the cohesiveness among team members, exploring alternative positions, increasing the involvements of everyone affected by the conflict and enhancing the decision-making process (Capozzoli, 1995; Klein, 1993; Shapiro & Dempsey, 2008).

Mature communication refers to the ability team members have to communicate clearly. They do this by articulating ideas and providing compelling reasons for their ideas, listening without interruption, clarifying what others have said and following through with constructive responses. Along with communication, a team's common understanding of individual's expected roles entails role clarity. The absence of role clarity often causes misunderstandings regarding the tasks of the team.

Accountable interdependence implies a mutual dependence and respect that all team members have, in terms of the quality and quantity of everyone's work within the team. Clearly defined goals are specifiable, commonly agreed upon statements that define the actions to be taken by the team. It is imperative that all team members know and understand what must be done by the team, collectively. Also, the goal needs to be tied to specific objectives that all team members are committed to and participate in as the team progresses toward achieving the goal.

Common purpose is related to the knowledge and understanding by team members of why the team is there and why it was assigned the specific task. Associated with common purpose is the definition of roles, or role clarity. Role clarity implies that all team members know, understand, and respect the position of each member in their task. Role clarity allows team members to recognize how to complement the skills and efforts of each other to make the team effective.

Psychological safety is defined as a shared understanding among team members that the team is safe for interpersonal risk tasking. It refers to an individual's sense of confidence that the team will not act against them for expressing their viewpoint with the team. Sense of trust and respect are the main elements that support psychological safety.

Integrating all seven effective team constructs and attitude, Ruiz and Adams (2004) designed and administered a teamwork effectiveness questionnaire that asked specifically about student perceptions of team experience. After administering the survey to senior students enrolled in seven different engineering design courses, they found that attitude toward teamwork is highly related to each of the seven characteristics considered to be essential for teams to achieve effectiveness. Six of the seven characteristics were shown to contribute to explained variance in attitude; conflict resolution was not found to contribute to the explained variance; however, it is possible that productive conflict resolution is embedded within the other variables. Their multiple regression analysis indicated that mature communication, accountable interdependence, psychological safety, common purpose, and role clarity contributed to the prediction of perceptions toward teamwork.

Engineering Practice

The practice of engineering involves the integration of the process of problem-solving and the specialized knowledge that enables the process (Sheppard, Colby, Macatangay, & Sullivan, 2007). More explicitly, engineering practice is the culmination of using professional , interpersonal, and independent thinking skills to solve ill-structured engineering problems (Jonassen et al., 2006). Seering (2009) operationalized professional skills as: professional ethics and integrity, responsibility and accountability, and continuous learning; personal skills as: initiative and willingness to take risks, perseverance and flexibility, creative thinking, and time/resource management; and independent thinking skills as: setting project goals, ability to extract and evaluate relevant knowledge, and maintaining confidence in one's own skills and abilities.

Engineering practice is more than simply connecting process with knowledge. It involves complex, thoughtful, and intentional integration of problem-solving process and knowledge that ultimately leads to a meaningful end (Sheppard et al., 2007). Many engineering students hold an unrealistic view that engineering practice is synonymous with only technical problem solving, even when they've completed design projects (Sheppard et al., 2010). To address this misconception and provide students engineering practice development opportunities, engineering education programs are integrating more cognitive apprenticeships (Collins, Brown, & Holum, 1991; Dennen & Burner, 2008) that expose students to professional practice through carefully staged and monitored steps.

In this study, engineering practice is performed through student design team's effective integration of problem-solving as a team and knowledge utilization that leads them to a successful demonstration of their final cornerstone design project. To be successful, student design teams are required to design two 3-dimensional printed parts, program a microcontroller, and compose a final team generated written technical report detailing the team's design process and outcomes of design. While many other components of engineering practice were necessary throughout the team's problem-solving process, the meaningful end culminated with the final cornerstone project products and demonstration.

Teamwork Perceptions

Teamwork perceptions are defined as a team's shared belief in its communal capabilities to organize and execute the necessary action to achieve given levels of attainment (Bandura, 1998). The performance and effectiveness of teams is strongly influenced by the individual team member's initial perception toward the use of team as a mechanism for a successful collective learning experience (Lent et al., 2006). In the educational setting, positive teamwork experiences result from intentional instructor guidance on how to work effectively (Oakley et al., 2007). When the student teamwork experience is positive, student's perceptions of their quality of learning from the course is also positive (Oakley, Felder, Brent, & Elhajj, 2004)

Human motivation, self-regulation, and performance are all psychological and social processes that can be understood through social cognitive theory (Bandura, 2011). There has been a large sector of research devoted to relating social cognitive variables, especially self-efficacy, to various aspects of educational and career performance (e. g. Hutchison, Follman, Sumpter, & Bodner, 2006; Lent, Brown, & Hackett, 1994; Pajares, 1996). This scholarship is mainly focused on the relation of social cognitive variables and outcomes obtained by students and employees as individuals. This focus is reasonable since most educational and vocational psychologists are typically concerned with optimizing development and remediating issues of individuals. In addition, the predominant reward system in educational and vocational systems tend to be linked to the performance and achievement of an individual (i.e., grades, salaries). However, group projects and activities continue to grow in use and attention among educational and vocational academics, since team experiences are growing in popularity as approaches to learning and working (Stajkovic & Lee, 2001).

Even though the research on social cognitive theory has accentuated individual constructs (i.e., self-efficacy) and outcomes, the theory is also involved with how people work together within teams or social units. **Collective efficacy**, for example, is a key cognitive element that may help explain how groups behave, for better or worse. Bandura (1997) defined collective efficacy as a "group's shared beliefs in its conjoint capabilities to organize and execute the course of action required to produce given levels of attainments" (p. 477). Alternate to self-efficacy, which involves a person's beliefs about their own ability to perform behaviors individually, collective efficacy refers to group members' aggregate beliefs about how they can perform as a unit. The research on collective efficacy has not grown as rapidly as that of its counterpart, self-efficacy, however it has proven to be a very flexible group-level explanatory construct; applicable with diverse group sizes, function, and setting (Stajkovic & Lee, 2001; Stajkovic, Lee, & Nyberg, 2009).

Collective efficacy hasn't yet been applied within the context of engineering education. However, a focus on student team development and experience of effective collaboration, problem-solving and team skills is of great importance. The use of teams in engineering education allows teams an enhanced learning process that enables the development of student's skills at managing team engagement. Teams also allow students the opportunity to work on more realistic, ill-structured engineering problems as these types of problems often require multiple viewpoints (Jonassen, 1997). Team dynamics, however, have the potential to present distinctive challenges for students and professors, such as how to handle interpersonal conflicts and ensuring all students are engaged and contributing to the process (Brannick, Roach, & Salas, 1993; Tesluk & Mathieu, 1999).

This study examines engineering student's perceptions of teamwork to better understanding the effectiveness of a makerspace, TBL experience. Positive perceptions during and as a result of the learning experience have implications for the trajectory of an engineering student's degree and engineering career success (Felder & Brent, 2004; Felder, Felder, & Dietz, 1998; Lent et al., 2006).

Theoretical Framework

The theoretical framing for this study parallels the empirical literature of engineering performance and teamwork perceptions described above in the previous sections. The following sections provide the literature that underpins the empirical literature of makerspace learning and TBL structures. Starting with a description of learning as an experience of social, situated nature, the necessity of the makerspace learning environment is formalized. The sections that follow present the effects of learning environment that informs experience. A conceptual framework is presented at the end that connects the empirical and theoretical literature into a structure in which this study is grounded.

Learning through Experience

According to John Dewey (Archambault, 1964; Dewey, 1938), education is the fundamental means by which a society progresses and reforms. The purpose of education is to successfully prepare each student to participate in and contribute to society. Thus, learning experiences must integrate the personal needs and life experiences of the individual and, since schools are social institutions, they must reflect the life of a student outside of the classroom. Students who find such experiences beneficial are able to learn; those who do not will get by as best they can (Dewey, 1938).

Dewey's (Archambault, 1964; Dewey, 1938) beliefs of education involve a theory of experience based on two principles, stability and collaboration. The premise of stability suggests that prior experiences influence present experience, a person is transformed by their present experience, and present experience impacts the type and quality of future experiences. This continuity between past, present, and future suggests that academic, tangible, and ethical growth that results from each experience should be educational in purpose and influence, as there are no neutral experiences. The quality of the current experience either encourages or restricts future growth and development of the student.

Dewey's philosophy of education and his principles of stability and collaboration provide pedagogical foundation for structuring learning environments. This stance is especially important for a curriculum as rigorous and strenuous as engineering. Freshmen usually find it difficult to synthesize content learned in all their first-year courses, such as: chemistry, humanities, physics, calculus, and English. The expectations of their engineering curriculum, perceptions of the engineering profession, and their everyday life can mean many students find acclimating to college to be particularly difficult as an engineering student.

Dewey's experience theory was proposed in the early part of the twentieth century and continues to have relevance and influence in education today. It served as a powerful prelude to the constructivist philosophy of cognitive and social psychology in the middle to latter part of the twentieth century. Constructivist epistemologies, like those of Piaget (1972) and Vygotsky (1978) expanded Dewey's theory of experience by integrating it with a cognitive perspective of how students' engagement with the environment enables metacognition and growth.

Sociocultural Learning. Sociocultural theories of learning posit social and cultural interactions as most important in the construction of knowledge. Within this framework, language and cultural tools help shape thinking and higher cognitive understanding (Vygotsky, 1978). While Vygotsky was one of the first developmental psychologists to pose a theory that explained cultural influence on learning, educational literature has continued to support the argument that culture has great influence on the cognitive development of students (Mahn, 1999).

Vygotsky examined human development as a transformation process of individual functioning as various forms of social practice become internalized by individuals (Wertsch, 1985). By studying human action in its developmental context, Vygotsky aimed to demonstrate how various individual mental functions have origins in social activity (Vygotsky, 1978). To him, the "transition from a social influence external to the individual to a social influence internal to the individual…is at the center of our research" (Vygotsky, 1960, p. 116). Vygotsky argued that human activity could only be understood in the context of culture and the use of cultural tools or signs. Cultural tools and signs, Vygotsky noted, "alters the entire flow and structure of mental functions" (Vygotsky, 1981, p. 137). Sociocultural theory emphasizes the use of cultural tools and co-construction of knowledge with mentors. Cultural tools may include physical objects like telephones or computers or symbolic tools like language, signs or symbols (Wertsch, 1991). Tools ultimately help to facilitate thinking and are used to organize thoughts, memory, learning, and behavior. As children mature, concept development continues, and their cultural tools continue to evolve (Vygotsky, 1978). Social interaction internalizes cultural tools and higher-level thinking. Learning, therefore, can be defined by the communities in which learning occurs (Wenger, 1998).

Situated Learning. Situated learning, also referred to as situated cognition (Brown, Collins, & Duguid, 1989), suggests that learning is grounded in the social, historical, and cultural experiences of the learners (Lave & Wenger, 1991; Wenger, 1998). Situated learning elevates the community, viewing the engagement of individuals as the primary mediator of learning, instead of language as Vygotsky did. A learning community consists of a group of diverse individuals, often focused on a specific activity that results in acquisition of new skills and knowledge (i.e., learning). Participation in a community implies that learners engage with other individuals as they progress toward mastery of an activity or practice. The greatest benefit of situated learning is the focus of keeping learning in context. Lave and Wenger (1991) have criticized formal education systems for their decontextualization of learning by presenting disjointed concepts, separating the learning of concepts from practice.

Learning, within a situated learning context, is always positioned in the cultural and historical context and defined as a social practice (Brown et al., 1989). Situated learning maintains that learning means further participation in a community of individuals that are learning and supporting one another (Lave & Wenger, 1991). Two of the main components of situated learning to an individual is practice and identity (Wenger, 1998). Social practice implies action and describes the ways in which we interact with the world. Practice considers real life context, as well as social systems and shared tools around which the group is constructed. Identity describes the impact of learning on the individual.

Practice as a Learning Outcome. A practice can be thought of as a skill or trade, like cooking or teaching, or it could be a profession, like engineering. Engaging in practice indicates participation in the activity while also being aware of the social and historical context of the activity. Practice can also incorporate cultural tools, similar to those described in Vygotsky's sociocultural theory (Wenger, 1998).

According to Wenger (1998), learning is the outcome of practice. Individuals transform as they enter and exit the practice; the work they do leaves a lasting mark on the practice that may change the group and its history. The learning that transpires is represented by the cumulative engagement of members, their understanding of the activity, and the development of performance and language that are specific to the practice. Learning is what drives the practice, and the practice is the expression of the history of what was learned.

Theoretical Connections to Current Study

Key elements of this theoretical framework meld the sociocultural, situated learning environment with a learning experience based on the practices and interactions that, over time, develop a community experience. A community, for this study, consists of students (situated in teams), the graduate teaching assistants, engineering faculty, and the socially shared resources. From this theoretical grounding, teamwork is reinforced repeatedly as a necessary learning experience element that is enhanced by the social and situated features present in a makerspace learning environment. The socially shared repertoire of resources, including experiences, stories, tools, and ways of addressing recurring problems suggest that positive success in establishing a shared practice can only be facilitated through support in the structure of the environment (Brown et al., 1989). The structure of the engineering design course theoretically positions teams of students to engage and experience gains in teamwork perceptions as they engage with one another to successfully perform and function to solve the ill-structured design problem nested within the TBL environment.

This study aims to empirically determine if the makerspace learning environment coupled with a TBL experience was successful in promoting engineering performance and gains in teamwork perceptions.

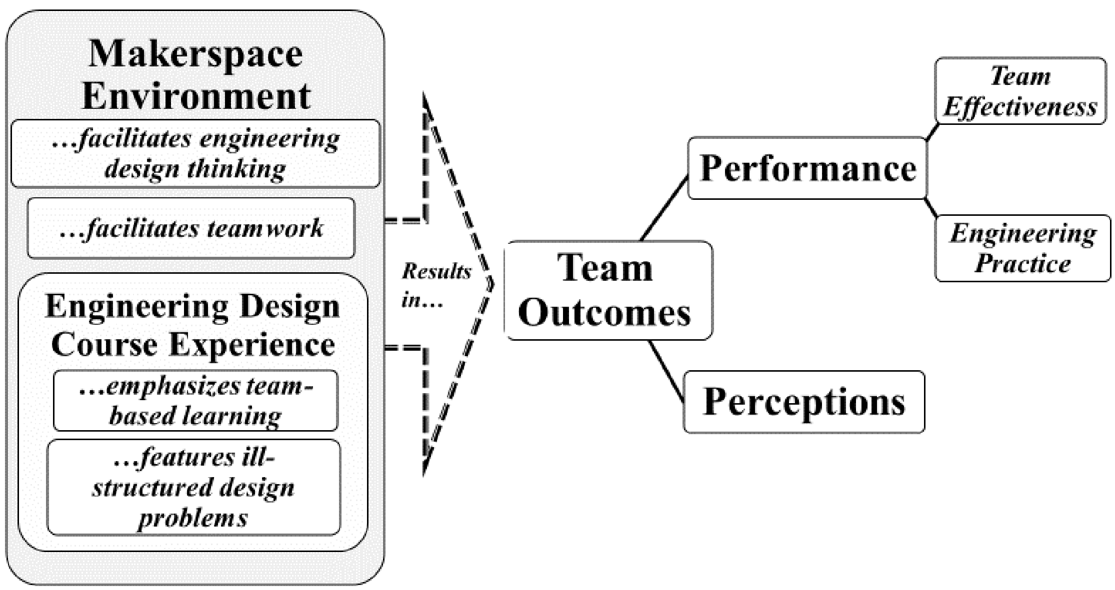
Conceptual Framework

The conceptual framework underpinning this study is built on the inherent features of teamwork and engineering design thinking present within a makerspace learning environment. The components of the engineering design course experience enhanced by the TBL and ill-structured design problem drive the resulting student team outcomes that coalesce around team perceptions and performance. Figure 2-1 is a pictorial depiction of this study's conceptual framework. The figure outlines the inherent makerspace environment features that support the facilitation of engineering design thinking and teamwork. Components of the team-based, engineering design course learning experience are nested within the makerspace as a depiction of the situated structure of the course in which students experienced ill-structured problem solving. The resulting team outcomes are exhibited in two outcome domains: performance and perceptions.

Team performance is made manifest through a design team's effectiveness in successfully completing all requirements for the final cornerstone project. Engineering practice performance is manifest in the technical quality of specific engineering tasks (details in the measurement section of next chapter). Finally, each student's perceptions of their team's functionality and performance captures the perception domain of the course's team outcomes.

Figure 2-1

Conceptual Framework



Study Boundaries

This study is limited to the exploration of teams' performance at the team-level (i.e. design project and team effectiveness) and to what extent the learning experience in the makerspace promoted gains in the perceptions of students about teamwork and effective team charactertistics. This study connects and cross-compares metrics, looking for patterns or unique cases, of performance (externally judged by GTAs) with teamwork perception (internally generated by each student).

This study is not designed to extract details of group dynamics within and among the teams of students. That is to say, this study does not explore specific elements of the course that impact teamwork performance or perception (i.e., building the cornerstone windmill, designing a 3D printed part, programming, technical writing, etc.).This study also does not seek to locate the reasons behind team dysfunctionalities or individual's reasons behind their perceptions of teamwork. Instead, this study bounds its perspective on how the set of course experiences as a whole do or do not affect teamwork perception and engineering performance.

Limitations

Limitations are discussed in two main aspects of the research: methodological decisions that restrict the ability to extract experiences of individual students, and potential confounds with how the cases were constructed. The field of making in education is very much still in its infancy, and the research is also still in an *exploratory* stage. Given this stage of the knowledge in the field, this study was designed to address the *how*-based exploration that underpinned the research questions to acquire a general sense of a phenomenon (team learning in an academic makerspace) that is mostly unfamiliar and little-understood in engineering education. This study was primarily quantitative in nature, extracting patterns and drawing conclusions about groups of students rather than investigating specific experiences and outcomes for individuals. Thus, one key limitation of this study is that it does not capture the impact and experiences of individuals as they experienced the team dynamics. So, while this study can offer evidence for how teams functioned and how aggregate team perceptions of large groups of students may have been impacted by the makerspace experiences, it cannot extract experiences of specific individuals. Thus, for example, this study is unable to offer evidence for how individuals identifying within various demographic groups (e.g., first generation status, gender identity, race identity, etc.) might have experienced the teamwork aspects of the makerspace

An additional limitation is related to possibilities for how the six classes (cases) were formed. There may be some systematic variation in which students would enroll in each of the six course sections that served the research as the six cases. In particular, enrollment is likely affected by the day and time in which each class was scheduled, so that the makerspace class would fit within the other classes these students were taking. Any systematic variation in logistical availability (e.g., if students who might be a step behind in their calculus course-taking sequence would find one or more class times to be more readily available due to the scheduling of their required next calculus course), could result in the six cases being composed of students who might have some systematic variation in traits.

CHAPTER III: RESEARCH DESIGN AND METHODOLOGY

The purpose of this chapter is to articulate the methodology of this study. The context of the study, research design, study participants, instrumentation, data collection approach, and data analysis will be explained. This study employed a convergent mixed methods design, aligning the conceptual framing with the methods of data collections and analysis to best answer the research questions. The data set primarily consisted of quantitative data to extract patterns and conclusions across the entire cohort (*N=488, 126* teams) specific to performance and perceptions, while qualitative data was collected concurrently and used to illustrate the quantitative measure of team effectiveness (described later in the chapter).

Context of the Study

Historical Underpinnings

In Fall 2016, the engineering fundamentals department at the University of Louisville J.B. Speed School of Engineering changed how first-year engineering students experience an introduction to the practice of engineering. Prior to the change, the first-year engineering student's introduction to the practice of engineering was a single course comprised of discussions and team-based explorations designed to promote student's conceptual understanding of the practice of engineering. Among the activities for the introductory, single course were case study analysis of engineering design challenges and collaborative teamwork assignments that focused on the engineering profession. While the course served as an obligatory introduction of first-year engineering students to the profession of engineering, the overall first-year student experience needed a "real world" way to engage and prepare students for the engineering profession. Missing was an integral, developmental experience that would instrumentally move first-year engineering students closer to the practice of engineering.

For students entering the engineering degree program, many expressed a common perception that the practice of engineering involved aspects of designing and building, based on procedures that incorporate creative and critical thinking. This perception resonated with the leadership of the engineering school, as funding was allocated from the University to create a makerspace learning environment. Additionally, the engineering school found great value in aligning coursework for all first-year engineering student; thus, a curriculum revision committee was formed to explore a more consistent first year experience for all engineering students. The focus of the curriculum revision committee was to provide guidance toward a coursework plan that would engage all first-year engineering students in learning experiences that connect engineering practice competencies through the development and performance of effective teamwork.

The curriculum redesign brought the first-year engineering student experience from a required, one-course (2-credit hour) commitment to a two-course (4-credit hour) sequence of courses, spanning two-semesters. The learning objectives for the two-course sequence expanded the content focus for all students to include prior objectives (i.e., engineering professionalism, problem solving, and teamwork development) as well as additional objectives (i.e., graphic design, computational communication, critical thinking, and ethics). Engineering graphics, for example, is a concept that is essential in the engineering workplace; however, prior to the curriculum redesign, students could only gain that experience if they took an additional course.

Coursework Components. The first course of the curriculum redesign, referred to as engineering methods, serves as the initial entry to the practice of engineering and engineering design process. The second course of the redesign, called engineering design, is the immersion of student engagement with teamwork and engineering design process. This second course, engineering design, is the specific setting for this study. The engineering design course integrates iterative engineering design with engineering practice, effective use of teamwork, and creative problem-solving into a final team performance project, the cornerstone team project. The cornerstone team project is initially the same for all student design teams; what differentiates the student teams is their creative designs to meet the criteria and constraints necessary to operate a functioning windmill efficiently and effectively.

Like the engineering design process, the refinement of curriculum, course structure, and classroom procedures have iteratively evolved over time. With each iteration the engineering design course details have been slightly modified with the goal to improve by streamlining many resources for students and strengthening the communication of learning objectives to students. From the beginning of the curriculum redesign and throughout each iteration, the same lead engineering faculty member has maintained the position of head instructor and curriculum designer. At the time of this study, the engineering design course curriculum was in its third iteration. All changes and modifications were made with the intent of improving the first-year engineering students' learning experiences and perceptions of teamwork and engineering practice.

Engineering Design Course Description and Setting

In the Spring of 2019, the engineering design course was starting its third semester since the initial curriculum redesign. Each iteration of course revision brought the engineering design course closer to an overall, immersive learning experience that involved engineering students in critical thinking processes, writing, and debugging computer programs, justifying technical solutions, and effectively performing team functions and problem-solving. The instructional leadership for the spring semester's engineering design course included: the lead engineering faculty member, a team of four additional engineering faculty members, and six engineering graduate teaching assistants (GTAs).

The curriculum and instruction structure of the engineering design course was progressively scaffolded. The first half of the semester was heavily laden with guidance and resources, including: online instructional videos, clearly outlined and provided lesson plans, and instructional activities. At the midpoint of the semester the course began a gradual release of responsibility (Fisher & Frey, 2013) with the retraction of resources and the shift over to full engagement with the ill-structured, 'wicked' (Jonassen et al., 2006; Rittel & Webber, 1972) design problem, presented to students as the cornerstone design project. Tying back to the essential elements of TBL (Michaelsen & Sweet, 2008) the engineering design course experience continued to include: multidisciplinary teams, individual and team accountability elements intentionally structured into assignments, instructors and GTAs regularly provide feedback, and the central team task was designed to bolster team efforts over individual efforts.

Participants

This research was conducted at the University of Louisville, a research-focused, large, metropolitan university. Participants in this study were enrolled in the second semester of a required first-year engineering design course. To enroll in this course, students must have successfully completed the required first semester course, engineering methods, as a prerequisite.

Engineering Student Participants. All engineering students enrolled in the engineering design course during the 2019 Spring semester were invited to participate in the study. 488 students, most in their first year of engineering coursework, were distributed based on their course registration into one of the available six engineering design classes. Each class had an enrollment ranging from 66-92 students and within each class were 17-24 student design teams (see Table 3-1). Each team was made up of 3-4 students and consisted of varying engineering disciplines. Table 3-1 provides these totals, per class.

Table 3-1

Engineering design course totals per class

	Engineering Design Class	**Number of student design teams**	**Number of engineering students**
Engineering Design Course	Class 1	*17*	*66*
	Class 2	*22*	*86*
	Class 3	*23*	*90*
	Class 4	*24*	*92*
	Class 5	*21*	*82*
	Class 6	*19*	*72*
Totals	*6 classes*	*126 student teams*	*488 Engineering students*

Student membership on teams was generated by the lead engineering faculty, based on guidelines to ensure no minority isolation (i.e., gender, race, and ethnicity) and assurance of as much variation on a team among engineering disciplines as possible. Some ethnic and racial minorities are at a higher risk for dropping out of college, and women are at higher risk than men in specific curricula (e.g., engineering), with most students leaving their program of study in the first two years (Seymour & Hewitt, 1997). Studies have shown that when members of minority groups are isolated in project teams, they tend either to adopt a less interactive role within the team or are relegated to such roles, thus losing many team interactivity benefits (Heller & Hollabaugh, 1992). Oakley et al., (2004) provided guidelines to avoid the impact of isolation that included forming teams in freshman and sophomore engineering courses that include all non-minority individuals or maintaining a minimum of 2 minority individuals or more. The team compositions for each class are provided in Table 3-2. Teams counting as non-minority gender and race were aggregated in the non-minority column. Teams consisting of members from groups identified at-risk of drop-out (Armstrong & Thompson, 2003; Astin, 1993; Swail, 2003) either of minority race (i.e., African American, Native American, or Hispanic) or minority gender (i.e., female or non-identifying) were aggregated in the minority column with a provided description of the configuration of minority status within the teams.

Table 3-2

Course non-isolation team compositions per class

Design Class	Number of Teams	Number of non-minority teams	Number of minority teams	Description of minority team configurations
1	*17*	*11*	*6*	1-team of four females. 5-teams, all male, with 2+ minority races.
2	*22*	*10*	*12*	11-teams with 2+ female; two of which with 2+ minority races. 1-team, all male, with 2 minority races.
3	*23*	*8*	*15*	13-teams with 2+ females. 2-teams, all male, with 2+ minority races.
4	*24*	*8*	*16*	14-teams with 2+ females; two of which with 2+ minority races. 2-teams, all male, 2+ minority races.
5	*21*	*12*	*9*	7-teams with 2+ female; two of which with 2+ minority races. 2-teams, all male, with 2+ minority races.
6	*19*	*9*	*10*	8-teams with 2+ females; two of which with 2+ minority races. 2-teams, all male, with 2+ minority races.

There are 7 engineering disciplines available for engineering majors to choose from within the college of engineering, including: bioengineering, chemical-, electrical-, computer-, industrial-, mechanical-, and civil/environmental-engineering. Teams were crafted so that each team was multidisciplinary in membership, and an intentional effort was made to ensure minority students, considered to be underrepresented in the field of engineering, were placed together on teams. Table 3-3 provides the composition of engineering majors, per class, as reported by students through the first administration of the teamwork perceptions survey.

Table 3-3

Engineering majors per class

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Bioengineering	*1*	*7*	*13*	*14*	*8*	*2*
Chemical	*1*	*4*	*7*	*13*	*9*	*16*
Civil and Environmental	*5*	*16*	*12*	*6*	*10*	*9*
Electrical and Computer	*4*	*1*	*16*	*11*	*19*	*6*
Computer Engineering and Computer Science	*45*	*31*	*3*	*12*	*5*	*8*
Industrial	*3*	*4*	*10*	*7*	*5*	*6*
Mechanical	*9*	*20*	*25*	*26*	*22*	*21*
Undecided	*0*	*1*	*0*	*1*	*1*	*1*

Graduate Teaching Assistants. Each class was assigned a GTA responsible for grading all student assignments, maintaining communication and announcements to students, and daily monitoring of class activities. While two engineering faculty were also assigned to each class, GTAs held the oversight role within the course structure. Classes 1, 4, and 5 were assigned GTAs of non-minority status, both in gender and race. Classes 2, 3, and 6 were assigned GTAS of minority status in gender, not race. The process of determining GTAs for the design course was executed carefully through a broad recruitment and thorough selection process. Specific attention was afforded to ensure representation of minority gender and race groups held by GTAs; the most qualified senior applicants were chosen.

GTAs served as a resource and content facilitator, interacting with engineering students in a systematic, consistent, and intimate manner. The GTAs were best suited to provide insights and evidence-based perspective in terms of student and team engagement and their effort in course specific activity. Due to the GTA’s intimate knowledge of each class's student and team composition, the GTAs (instead of faculty members) served as a primary source of some of the data collection for this study.

Researcher Reflexivity and Positionality. As researcher of this study, I felt it necessary to explain my position as a white female doctoral candidate with experience in the field of engineering and as a STEM educator. This positionality is important to describe as a portion of the analysis is qualitative and much of the overall interpretations that will be applied to results are informed by my experiences and expertise. I have spent the last four years working as a graduate research assistant within the engineering fundamentals department of the college of engineering – this is the department responsible for developing and delivering the engineering design course at the core of this study. This position has afforded me the opportunity to work closely with many of the engineering faculty members who were involved with the curriculum redesign and those that maintain lead faculty roles within the engineering design course.

It was through another research project and the gracious offer by the lead engineering faculty member, that this opportunity to explore the makerspace learning environment of the engineering design course emerged. Through my ongoing role as a research assistant within the engineering fundamentals department, I have acquired intimate knowledge of the first-year engineering student experience and the coursework that is associated with it. I have examined and explored first-year engineering student retention, engagement, and interest in various engineering calculus courses as well as exploring the various holistic structures of the first-year engineering student experience. Each of these engagements and investments has led me to a continual desire to explore aspects of student learning through the practice of engineering, especially with teamwork.

I was a middle and secondary (grades 8-12) math, science, and engineering teacher prior to being a graduate research assistant. I designed and implemented curriculum that was framed by the evidence-based teaching strategies that lead to student's engagements with active and collaborative learning. Each classroom learning environment I taught in could be characterized as an academic makerspace; equipped with student computers, 3D printers, various test and measurement equipment, and numerous resources for the many project-based assignments and activities that I integrated into the curriculum.

The curriculum I wrote, and my pedagogical approach was grounded in the overarching philosophy of the engineering design process. Having some professional engineering experience prior to teaching, I found that the iterative and elegant nature of the process of engineering design was applicable in any work or life scenario. As a female working and teaching within various STEM fields, I often far exceed the expectations others apply to my capabilities by continually seeking out explanations to queries presented by the consequences of shortsighted decisions. Throughout my personal and professional experiences, I came to view the world as an on-going design process that required dissecting problems, asking questions, generating ideas, examining the possibilities, seeking feedback from others, and deciding on a solution that inevitably would require innovation.

While a secondary teacher, I also lead professional development experiences for various organizations, training teachers (1^{st} through 12^{th} grade) in the use and practice of the engineering design process. During those trainings, I was always able to find inspiration observing teachers of all academic content develop their own understanding of the engineering design process. However, the spaces in which these trainings were often conducted were not always inspiring. Whether it be the lack of resources, space available, or the dilapidated aesthetics, I identified the necessity of a creative and open space such as the makerspace as integral but not necessary for learning to occur. My pedagogy and appreciation of diverse thinking was impacted by the training experience, and I was revigorated as I returned to my own classroom learning environment. My appreciation of teamwork and collaboration has increased over time as I find my most innovative and gratifying work is through collaboration and contributing to an effective team.

Research Design

Methodological eclecticism is a term defined as selecting and then synergistically integrating the most appropriate techniques from a myriad of qualitative, quantitative, and mixed methods to more thoroughly investigate a phenomenon of interest (Tashakkori & Teddlie, 2010). To answer the research questions most fully for this study, both quantitative and qualitative perspectives were necessary. The study was quantitatively driven to extract patterns and conclusions for the entire cohort (*N=488, 126* teams), while qualitative data served to illustrate the quantitative perspective within the construct of team effectiveness.

A convergent nested study design (Creswell & Clark, 2017) was chosen due to the nested context (i.e. individuals nested within student design teams) and the intertwined nature of teamwork and its associated constructs. The convergent integration of data involved merging the results from the quantitative and qualitative data so that a comparison could be made, and a more complete understanding emerge than that provided by the quantitative and qualitative results alone.

The engineering design course was comprised of six classes, each class being divided into 17-24 student design teams of 3-4 engineering students (see Table 3-1). The six classes were held on various days and at different times during the day.

For this study, each class was treated as a distinct case to allow for cross-case comparison (see Table 3-1). The class is considered a case, since the interactions among students and teams occurred within and due to the course schedule and class enrollment structure, but rarely to never did student teams tend to interact with different classes. It was also common for instructors to encourage engagement and interaction among student teams within their class. It was uncommon for students in different classes (held at different, non-overlapping times) to interact with each other in relation to the engineering design course's work, thus positioning each class to reasonably be an independent case with potential for interactions among the teams within the class. There are two foundational units of analysis for each case in this study: the individual-level and the team-level (see Table 3-4). Since this study is focused on the socially situated makerspace learning environment and the TBL experience, it is necessary that both units of analysis be considered to ensure understanding at both the individual and the team level.

Instrumentation and Measures

Team Effectiveness

At the end of the semester, guided by a faculty template, teams each made an oral presentation including a demonstration of performance of their final cornerstone design project. At the conclusion of all student presentations and submission of coursework requirements, GTAs completed ratings of each team's effectiveness as a team and efficiency of performance, based on both the final presentations and the GTAs perception of team functioning throughout the semester. The GTAs were asked to rate each team of their assigned class along three dimensions of team effectiveness: amount of effort put into the project, quality of the product, and how effectively the team functioned overall (Lent et al., 2006; see Appendix C). Each dimension was rated on a 3-point scale, with higher ratings reflecting better team performance and efficiency. Additional space was provided, per team, for GTAs to provide additional qualitative comments or explanation of the rating given.

In a prior study of collective efficacy and team performance, instructor ratings of team performance were moderately related ($r=.44$) to collective efficacy, moderately interrelated ($r=.43$) to student ratings of team performance, and team cohesion was found to be strongly related to both student and instructor ratings of performance (Lent et al., 2006). In a separate study, instructor ratings of student team performance were found as a way to alleviate inflated correlations between collective efficacy and team performance, when compared to student ratings on performance (Gully, Incalcaterra, Joshi, & Beaubien, 2002). The rating instrument used in this study followed similar performance criteria of prior studies that investigated student team performance and collective efficacy (Lee, Tinsley, & Bobko, 2002; Lent et al., 2006). This measure, the ***GTA rating of team effectiveness***, can be found in appendix C.

Engineering Practice

Two cornerstone design project scores were recorded for each team during the final demonstration day designated for each class. Student teams worked throughout the semester physically constructing, learning 3-dimension modeling, and practicing programming. Of the 13 weeks that made up the semester, teams were the given (per course syllabus) 9 weeks specifically designated for teams to work together to execute effectively and efficiently building a functional windmill with two, 3-dimensional printed parts (see Appendix D, score 1) and a microcontroller programmed to display 5 efficiency readings (see Appendix E, score 2). The instrument used to score each team was developed by the lead engineering faculty member. For validity, the additional 4 engineering faculty and 6 GTAs reviewed the criteria described for each performance outcome (i.e., score 1 and 2) prior to the final demonstration day of each class. The engineering faculty and GTAs evaluated the points allotted per criterion item, confirming their agreement. For reliability purposes, the course faculty and GTAs met prior to scoring student design teams and established consistent meaning of each criteria item to be assessed. The ***Cornerstone Project Design*** instrument used in the scoring of student design teams is available in appendix D.

Teams were also responsible for generating a final written technical report that detailed the design team's process and results of the cornerstone project design performance and demonstration. The written report rubric was comprised of three elements: technical document formatting, project design content, and an overall composition score. To enhance validity GTAs and faculty members reviewed the criteria for each element of the written report score. Reliability of the written report scores was strengthened by pairs of GTAs consensually scoring each team's written report. The ***Cornerstone Technical Writing Report Rubric*** can be found in appendix E.

Teamwork Perceptions

The ***Student Teamwork Perceptions*** survey consisted of questions pertaining to individual student's **collective efficacy** beliefs in their team and a forced ranking of **effective team characteristics** (see Appendix A, part 1 for collective efficacy and part 2 for team characteristics). The survey was administered at three-time points during the semester. The pre- and mid-semester surveys were administered during the beginning of each engineering design class, the post-semester survey was administered outside of designated class time during the final week of classes.

The first part on the student teamwork perceptions survey was a **collective efficacy** scale adopted from Lent et al. (2006), containing 9-items. In a scale validation study, Lent et al. (2006) administered an 18-item version, confirming the factor structure of the collective efficacy measure by identifying 9 items with high factor loadings ranging from *.83* to *.92*. Additional factor analysis with the 9-item measure further validated the factor structure among two samples, yielding coefficient alpha estimates of sample 1 and 2 to be *.96* and *.94*, respectively (Lent et al., 2006). Student participants were asked to anonymously indicate their confidence in their design team's ability to execute the 9 tasks successfully as a team, rather than how well individual team members performed. Sample items included "work well together even in challenging situations" and "adapt to changes in their team's capabilities" on a 10-point scale from no confidence (0) to complete confidence (10) – see part 1 in Appendix A (pre, mid, post).

The second part of the student teamwork perceptions survey asked students to rank **effective team characteristics** (Ruiz & Adams, 2003) in order of 'most important' to 'least important', based on their individual impressions of each characteristic. Examples of team effectiveness characteristics included "communicates clearly" and "establishes a common purpose/goal". See part 2 in Appendix A (pre, mid, post).

An additional measure of teamwork perceptions was through the collection of peer evaluations at three time points during the course. As a part of a syllabus requirement for the engineering design course, students were required to complete a ***Peer Evaluation of Team Member Effectiveness*** (PETME; see appendix B) at three timepoints during the semester (see Table 3-2). The PETME instrument was a modified version of the Comprehensive Assessment of Team Member Effectiveness, often referred to as CATME (Ohland et al., 2012).

The PETME instrument contained 4-items of important team functioning. The 4-items asked students to evaluate their teammates by: (1) contributing to the team's work, (2) interacting with teammates, (3) keeping the team on track, and (4) expecting quality of team product. For this study, these areas of evaluation provide insight into the student perceptions of teamwork. Peer evaluations create accountability to teammates and provide incentive for displaying good interpersonal skills and contributing effort to help the team achieve its goals (Cestone, Levine, & Lane, 2008; Levine, 2012). Individual accountability is necessary in TBL methods and when absent can lead to student's negative perceptions of teamwork (Finelli, Bergom, & Mesa, 2011; Oakley et al., 2007).

The items that comprise the previously formed CATME instrument emerged through extensive literature review and an instrument design and piloting process

(Loughry, Ohland, & DeWayne Moore, 2007). Following the piloting process, Ohland et al. (2012) developed a behaviorally anchored rating scale using the CATME dimensions of team-member contributions. The behaviorally anchored rating scale is beneficial because the ratings provide specific descriptors of observable behaviors at different levels of performance. This level of clarity in rating choices is intended to reduce ambiguity for respondents about what rating is appropriate; thus, providing more face validity than a Likert-scale without behavioral anchors. Students are provided with their self, anonymized peer, and average team rating on each of the dimensions as feedback (Loughry, Ohland, & Woehr, 2014). Based on exploratory and confirmatory factor analysis, the final CATME instrument had 5-items: (1) contributing to the team's work, (2) interacting with teammates, (3) keeping the team on track, (4) expecting quality, and (5) having relevant knowledge, skills, and abilities (Loughry et al., 2007).

The CATME instrument was modified by the lead engineering faculty to include the first 4-items providing alignment with the course learning objectives. The fifth CATME item related to relevant knowledge, skills, and abilities was not administered due to time constraints and the course syllabus included other team measures that provided evidence of knowledge, skills, and abilities. The PETME instrument also utilized Ohland et al.'s (2012) behaviorally anchored rating scale (see Appendix B), for the student choices of evaluation.

Data Collection

Data collection began in January 2019 and was completed by end of the Spring semester in April 2019. Data collected from this study was collected by the researcher and the lead engineering faculty member, as part of the normal class schedule. An overview table describing the stages of data collection is provided in Table 3-4. The engineering design course is structured so that the first 4 weeks of classes are filled with knowledge and skill building through course resources and highly structured learning experiences. After week 4, the resources and structure of learning experience gradually diminishes as student design teams engage with the ill-structured, ‘wicked’ cornerstone design project.

Table 3-4

Stages of Data Collection

Research Question	Week 2	Week 7	Week 9	Week 11	Week 15
1. Is a Makerspace learning environment effective for promoting student design team's engineering performance in…					
1a. Team Effectiveness?					**GTA rating of Team Effectiveness**
1b. Engineering Practice?					**Cornerstone Project Design** ○ 3-D printed parts ○ Programming **Cornerstone Written Report**
2. To what extent does the team-based learning experience promote positive gains in students'…					
2. …teamwork perceptions?	Pre-Course **Student Teamwork Perception Survey** ○ Collective Efficacy ○ Effective Team Characteristics	**PETME** 4-item teammate evaluation of effectiveness	Mid-Course **Student Teamwork Perception Survey** ○ Collective Efficacy ○ Effective Team Characteristics	**PETME** 4-item teammate evaluation of effectiveness	**PETME** 4-item teammate evaluation of effectiveness Post-Course **Student Teamwork Perception Survey** ○ Collective Efficacy ○ Effective Team Characteristics

Team Effectiveness

The six GTAs rated student design teams in 3 dimensions of team effectiveness at the end of the semester, during week 15 of the engineering design course. The GTAs rated each team within their assigned engineering design class using a 1-3 scale (see Appendix C), where 3 represented adequate evidence and 1 was no evidence. The first two dimensions rated by the GTAs pertained to the team's effective performance in the end-of-semester capstone project while the last dimension focused on the team performance throughout the semester. The third dimension was deconstructed into 3-performance criteria: (1) communicating with one another throughout the semester, producing a result, and managing the process throughout the semester.

For validity in measurement, the 3 performance dimensions were reviewed by the researcher with the 6 GTAs in a group session, to verify a group-consensus perspective on the meaning of each rating score. This step was intended to enhance the overall validity and reliability of GTA ratings and allowed the researcher and GTAs to clarify and operationalize the meanings of each rating value for each performance criteria. As an additional reliability measure the researcher remained available during the time that each GTA completed their ratings to address any questions or uncertainty about the rating criteria. In preparation for analysis, aggregating these 3-dimension ratings will result in a total possible score of 5-15 for each team.

Additional space was provided on the instrument for optional GTA comments and explanations. The GTAs utilized the comments and explanations space, documenting specific characteristics of design teams or individual students that bolstered or limited a team rating. The section *Phase 1: Team Effectiveness* below describes the generation of initial coding themes, and the process for establishing interrater reliability between two independent, informed coders.

Engineering Practice

There were three scores that collectively represent the engineering practice construct. To assess teams on their cornerstone design project, a GTA and a faculty member observed the design teams present and demonstrate the functionality of their cornerstone project. The GTA and faculty independently scored the team's performance in design and programming, using the cornerstone project design rubric (see Appendix D). Following the team's demonstration of their cornerstone design project, the GTA and faculty consensually agreed on the scoring for each rubric item.

Cornerstone Design Project. The first feature of engineering practice was the performance in designing and printing *3D printed parts*. The possible scores for this measure range from 0-50. Each criteria item measures the team's ability to design, based on constraints, and perform within a specified timeframe (see Appendix D).

The second feature of engineering practice was the performance of programming. The possible scores for this measure range from 0-50 (see Appendix D). Each rubric item measures the team's use of course resources and execution of critical thinking to program a microcontroller to display specified outputs that correspond with the functionality of the design project.

Teamwork was an essential element of this measure as most engineering students on the student design teams had little to no programming experience and skillful use of team interaction was necessary to execute the required rubric criteria items. Successful team performance of engineering practice also indicates effective teamwork characteristics, such as communication and collaboration were incorporated. The Cornerstone Design Project integrated various physical, electrical, and software tasks that required all team members' full participation and efficiently functioning teamwork to meet deadlines and demonstrate a functional design.

Cornerstone Technical Writing Report. The written report feature of engineering practice was the team's collaborative compilation of a piece of technical writing, comprised of three elements: technical document formatting, project design content, and overall composition (see Appendix E). The written reports were submitted as a team through the course's online learning management system. GTAs scored each team's technically written reports in pairs using the written report rubric on a total scale of 0-100 (see Appendix E) and recorded their assessed scores for each rubric item.

Teamwork Perceptions

Teamwork perceptions were collected using two measures, each of which were administered at three time-points. Both measures (***Student Teamwork Perceptions Survey*** and ***Peer Evaluation of Team Member Effectiveness***) were administered as part of the typical engineering class procedure.

The ***Student Teamwork Perceptions Survey*** was administered using the online survey software, Qualtrics, at the beginning of class for the first two administrations. The first administration was during week two (see Table 3-2 and Appendix A) and the second administration was during week nine (see Table 3-2 and Appendix A). The third administration (see Table 3-2 and Appendix A), in week 15, was collected out of class due to end of semester limitations on class time. Announcements were made by the engineering faculty or GTAs at the beginning of class, during the third administration, to encourage students to complete the survey. At each of the timepoints, the survey was electronically delivered to the students via e-mail and announcement, sent by the researcher through the course's online learning management system. An opt-out option was provided and there were no implications to the student for not participating. The data, for all 3 administrations, was collected without identifying information thus the analysis of this data will be aggregated per class and used in cross-class analysis.

The second teamwork perceptions measure, ***Peer Evaluation of Team Member Effectiveness (PETME),*** was administered as a part of the course syllabus requirements. Each student was provided individual login credentials at the beginning of the semester, by the lead engineering faculty, and at three different timepoints (see Table 3-2) designated by the course syllabus, students were required to evaluate their teammates using the provided 1-5 behavioral description rating scale (see Appendix B). The data collected was used by the course as a participation grade; for this study, the data was collected as a teamwork perceptions indicator.

Data Analysis

These data were analyzed in three phases. The first phase analyzed the three constructs of this study (team effectiveness, engineering practice, and team perceptions) separately, for each of the 6 classes (cases). The second phase of analysis explored interactions across constructs within each case, then repeated six times for each of the separate cases. The third phase of analysis explored cross-case looking for patterns, similarities or uniqueness and intersections across-cases. Table 3-5 describes the phases of data analysis, providing a rationale for each phase.

Table 3-5

Phases of data analysis

	Description of Phase	**Rationale**
Phase 1	Within each case, each construct analyzed independently	Establishing construct metrics
Phase 2	Within each case, construct interactions are explored	Exploring performance and perception interactions
Phase 3	Across cases, systematic patterns within and across constructs explored	Pattern of construct interactions examined

The three constructs of this study (team effectiveness, engineering practice, and team perceptions) were measured in two different levels, due to the nested context and research design. The two team performance outcomes, team effectiveness and engineering practice, were measured at a team-level since both constructs are targeting a team's successful performance rather than an individual student's performance. The teamwork perceptions construct was measured at the individual student-level as perceptions are generated and held within an individual. Table 3-6, below, outlines the different levels of measurements and the instruments that assess each construct.

Table 3-6

Construct measures

	Performance		
	Team Effectiveness	**Engineering Practice**	**Teamwork Perceptions**
Team-level	GTA Rating of Team Effectiveness	Cornerstone Project Design Score with two parts Cornerstone Written Report Score	
			Perceptions
Individual (student)-level			Student Teamwork Perceptions Survey Comprehensive Assessment of Team Member Effectiveness

The sections that follow are organized to follow the phase sequence of data collection, described in Table 3-6.

Phase 1: Team Effectiveness

Quantitative: GTA Ratings

To analyze the construct of team effectiveness, the GTA ratings of the 3 performance dimensions (see Appendix C) at the team-level was generated, creating a total team effectiveness score ranging from 5-15. With a goal to create categorization of the teams in terms of their effectiveness, a histogram of the entire data set was generated (see figure 4-1). The histogram of aggregate GTA ratings was used to establish cut points for categories that best represented the data set as a whole. The distribution of team categorizations within each case was presented as part of phase 1 analysis. The team categories, per case, were used in the cross-construct analysis for Phase 2.

Qualitative: GTA Rating Comments

In addition to ratings for each team, GTAs provided qualitative comments outlining their rationale for each rating. These comments were coded based on the content and contextual relevance, using constant comparative method through analysis (Corbin & Strauss, 2015). Qualitative coding of comments took place just after the conclusion of the categorization process of the GTA ratings. That a priori knowledge and the previous experience with literature and "wisdom of practice" (Shulman & Wilson, 2004) guided the coding analysis to generate overall descriptions for labeling each of the three categories of GTA ratings. The initial themes per team, within each case, were constructed with effective team characteristics (Adams et al., 2002) in mind; while remaining open to the possibility of additional team characteristics emerging through GTA description in comment.

An independent coder was brought into the coding process to enhance validity and inter-rater reliability through a process of multiple coding (Barbour, 2001; Creswell & Clark, 2017). The independent coder was an unbiased, non-engineering focused doctoral student, trained by the researcher on the process of coding, guided by effective team characteristics (Adams et al., 2002). The independent coder was not aware of previous GTA ratings, the quantitative categories per case, and had no impressions of the qualitative GTA comments prior to coding. This means that coding was based only on what the GTAs wrote, as opposed to inferring about the comments based on what was observed or through knowing what was being referred too from daily experience with the cases.

Multiple coding (also known as interrater reliability) by the researcher and independent coder was performed independently, using the same data, seeking shared understanding of the meaning of the codes and checking validity of the codes as they were refined and clustered (Barbour & Barbour, 2003). Independent coding is often used in qualitative analysis and an accepted value of inter-rater reliability within the research community is 80% (Miles, Huberman, & Saldaña, 2018). The purpose of multiple coding in this study served two purposes, (1) to help assess the a priori codes against the GTA comments, and (2) "to furnish alternative interpretations and thereby to act as the 'devil's advocate'" (Barbour, 2001, p. 1116). The regularly occurring phrases, terms, and consequential language of GTA provided context of a team's effective or ineffectiveness (Miles et al., 2018). and were clustered together, generating themes. After the first round of coding responses (*n=126*) there was *91%* agreement, exceeding the acceptable inter-rater reliability percentage of *80%*. A discussion of the differences in code interpretation between the researcher and independent coder led to agreement of the effectiveness themes associated with the teams that comprised each of the quantitative categories (low, moderate, high). The themes from the comments were organized by the quantitative categories (low, moderate, and high), per team, to provide important conceptualization and context shared across cases (Gibson & Brown, 2009).

Phase 1: Engineering Practice

For each of the three identified features of engineering practice (i.e., design =0-60 points; programming=0-40 points; and technical writing=0-100 points; see Appendices D and E), descriptive summaries at the team-level, were first used to characterize the scores. Since each of the three features are scored based on points, to compare each of the features, three aggregate scores were calculated for each team and histograms were generated (for each feature separately, as well as an aggregate ‘engineering practice’ score on 0–200 point scale) to observe frequency distribution characteristics. As with the team effectiveness score, the data from all 126 teams across all cases were aggregated to explore the whole-group distribution. The histogram of the aggregate ‘engineering practice’ scores, across all cases, was used in the establishment of classification categories, based on natural cut points in the data. Following the establishment of categories, individual teams were classified within these categories. The frequencies of team codes, within each case, were used in the cross-construct and cross-case comparisons in Phase 2 and 3 analyses.

The histogram of the technical writing feature of engineering practice was also categorized in the same manner as the aggregated engineering practice score. The establishment of classification categories were based on natural cut points in the data. Following the establishment of classification categories, individual teams were classified within these categories and used in the cross-construct and cross-case comparisons in Phase 2 and 3 analyses.

Phase 1: Teamwork Perceptions

Teamwork perceptions were measured at two levels: individual student-level and team-level with two separate measures (student teamwork perceptions survey and the peer evaluation of team member effectiveness) at three stages of data collection (See Table 3-2). The following sections describe the analysis plan for each of the teamwork perception measures

Student Teamwork Perceptions Survey

Using SPSS version 27, the internal consistency of the 9-item, **collective efficacy** scale (question one in Appendix A) was evaluated through the calculation of an overall Cronbach's alpha. Through this reliability analysis individual item statistics were evaluated based on the fit of each item to the overall scale consistency. Since the scale was originally validated by Lent et al. (2006), the evaluation of factor loadings and Cronbach's alpha ratings at each timepoint, for the whole-group data set, confirmed criterion validity.

Graphical representations across administration timepoints, both at the student-level and within each case, were explored for any similarities and differences. Phase 3 of this analysis will continue with an exploration across cases to identify any patterns of collective efficacy beliefs within and throughout all cases. See Table 3-2 for an outline of these timepoint stages of data collection.

Student responses of ranking order among the 6 **effective team characteristics** were first analyzed with a frequency distribution. Using most important (1) to least important (6), the frequency of each ranking number for each characteristic informed the model distribution of the effective team characteristic categories. To determine any significant differences between characteristics, a chi-square test between team effectiveness characteristic rankings was used. Residuals for each cell in chi-square were also calculated to determine which cells contributed most when a significant difference was located. Using graphical and chi-square results, the differences within each case were explored among rankings of team effectiveness characteristics by level of importance. This analysis will extend across cases, into Phase 3 of analysis, to identify ranking differences among effective team characteristics, looking for patterns or discrepancies of high or low importance ratings.

Peer Evaluation of Team Member Effectiveness

The evaluation of team member effectiveness, provided by the 4-items of the PETME instrument used a multiple step process beginning with individual-level analyses, then aggregated to team-level results. The 4-item ratings, per teammate, were averaged for each team member to create a peer evaluation average at the individual-level. The individual-level averages, within each team were used to calculate a team-level discrepancy range. This range was generated by subtracting the lowest individual-level teammate evaluation from the highest individual-level teammate evaluation. This calculation of discrepancy ranges was replicated for each team, at each of the three timepoints, for all six cases.

Graphical representations for each case were created that show the discrepancy ranges within each case, across all timepoints. A higher discrepancy range indicated one or more teammate evaluations averages to be lower than that of at least one other teammate. Using the team-level discrepancy ranges, each case was examined across all three timepoints, looking for discrepancies indicating possible team dysfunction or presence of one or more ‘slacking’ team members. Graphical representations were used to examine discrepancy patterns at the team-level within each case, at each timepoint in Phase 1 analysis. The whole data set, across all cases at all timepoints were used to extract patterns of discrepancy in Phase 3 analysis.

Phase 2: Cross-Construct Analysis

The second phase of analysis, cross-construct, sought patterns within each case across the three constructs. Within each case, correlational associations of means were used to identify possible relationships among constructs. Concurrently, within each case, comparisons were conducted of the categories, developed in Phase 1, to compare across construct variables. The correlational and group comparison analyses were replicated six times for each of the separate cases. A more thorough explanation of the correlational and group comparison analyses is available in the next two sections.

Cross-Construct Correlations

Seeking relationships among construct variables, a Pearson's correlation coefficient and effect size (computed by r^2) determined whether there was an association between the constructs that consist of team performance and teamwork perceptions.

Team performance constructs were measured at the team-level unit of analysis and consisted of *team effectiveness* (GTA ratings, see Appendix C) and *engineering practice* (design, programming, and technical writing, see Appendices D and E). Guided by Phase 1 analysis, the aggregate GTA ratings (team effectiveness), the sum of the three (design, programming, and technical writing) capstone design project scores (engineering practice), and the technical writing were used as continuous variables in the correlation analysis. As is understood with correlations, influence for causation of one construct with another was not the goal. Rather, this exploration was to identify how strongly a pair of constructs are linearly related and change together, based on the constructs and data of this study.

Teamwork perceptions constructs were measures at the team-level and individual-level. *Collective efficacy* (see Appendix A, part 1) and *team effectiveness characteristics rankings* (see Appendix A, part 2) were measured at the individual-level, within each case. The collective efficacy measure was collected at the individual-level as an anonymous data set; therefore, collective efficacy means are unable to be transformed to team-level data for correlations analysis with team performance constructs. Additionally, team effectiveness characteristics were collected as an individual-level data set that consisted of 6-effective team characteristics, forced ranked, leading to a data set of 6-ordered rankings per individual. The ordinal nature of the data, without ability to transform into team-level data, prohibits correlational analysis with team performance constructs.

The only team-level measure of teamwork perceptions were the discrepancy ranges of the *peer evaluations of team member effectiveness* (PETME, see Appendix B), collected at three timepoints in the semester (see Table 3-2). A correlational analysis of the PETME discrepancy ranges, at each timepoint, was conducted with both team performance measures (team effectiveness and engineering practice), seeking relational patterns that denote linear relationships within case of steady growth of balanced teamwork perceptions denoted by decreasing team discrepancies.

Phase 3: Cross-Case Analysis

Cross-case (class) phase 3 analysis began with the Phase 2 cross-construct results from each case, with the purpose to identify patterns of interactions among constructs that are common or unique to a particular case. Analysis continued with Phase 1 within-construct results, deductively and holistically extracting abnormalities and consistencies.

For example, a case containing many teams of consistently "low team effectiveness" scores, when compared to the rest of the cases, may also have similar or different percentage of students with negative teamwork perceptions. Potential underlying reasons that might anticipate or predict these patterns will be discussed in the final chapter of this dissertation.

CHAPTER IV: RESULTS

This chapter presents results in the order of the three phases of data analysis. The first phase analyzed the three constructs of this study (team effectiveness, engineering practice, and teamwork perceptions) separately, for each of the 6 cases. The second phase explored interactions across constructs within each case, then repeated six times for each of the separate cases. The third phase explored across cases, seeking patterns of similarities and intersections cross-construct and cross-cases. Table 4-1 details the contents of each phase, in order of chapter presentation.

Table 4-1

Results chapter overview

Analysis Process	Contents	Rationale
Phase 1 Within each case, each construct analyzed independently	**Team Performance** - Sample Size, team-level - Team Effectiveness - Engineering Practice **Teamwork Perceptions** - Survey Response Rates - Collective Efficacy - Effective Team Member Characteristics Rankings - Peer Evaluation of Team Member Effectiveness	Establish construct metrics
Phase 2 Within each case, construct interactions are explored	**Team Performance** Team Effectiveness ↔Engineering Practice **Teamwork Perceptions** ↕ Peer Evaluation of Team Member Effectiveness **Team Performance ↔ Teamwork Perceptions**	Exploring performance and perception interactions
Phase 3 Across cases, systematic patterns within and across constructs explored	- Case 1, Different from the Rest - Technical Writing Sensitive to Team Functioning - Collective Efficacy Calibration with Experience - Consistent Recognition of Effective Team Characteristics	Pattern of construct interactions examined

Phase 1: Team Performance, Team-level Unit of Analysis

Sample Size

Team performance was comprised of team-level measures of team effectiveness and engineering practice. The data for each of these measures was collected at the team-level, and therefore the sample size within each case (class) is the number teams. Table 4-2 provides the sample size of number of teams for each case.

Table 4-2

*Team **Performance** Sample Size, team-level unit of analysis*

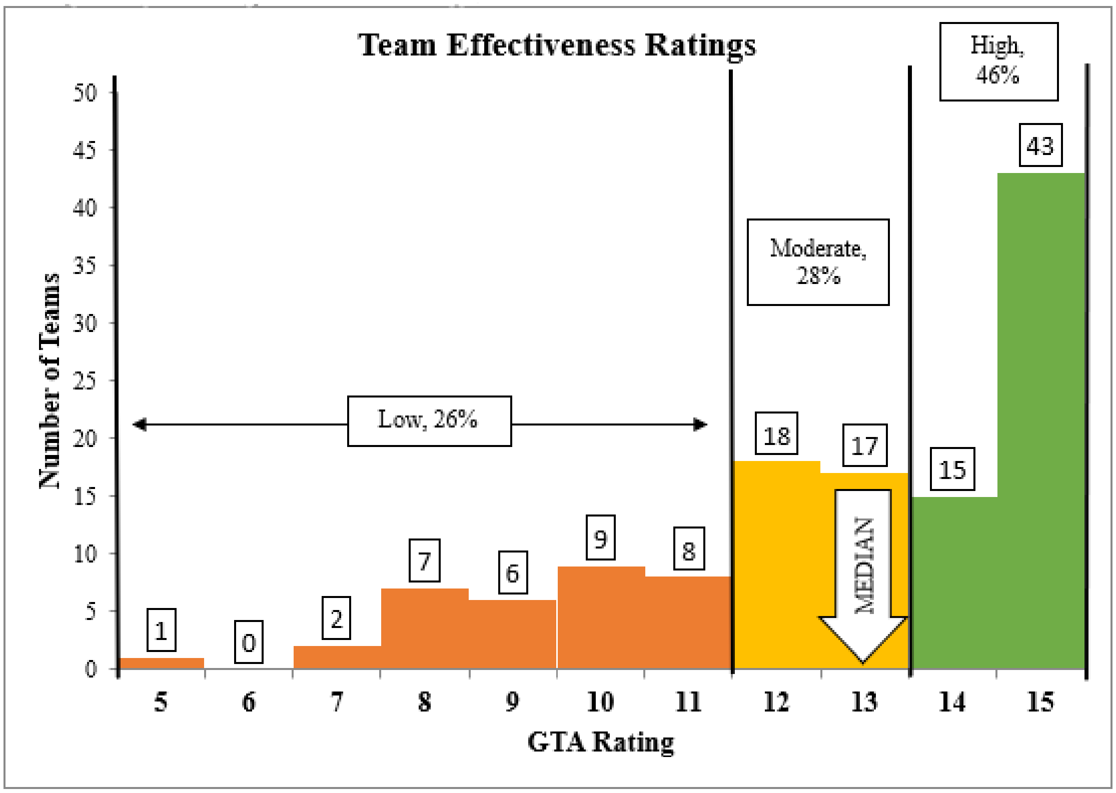
<table>
<tr><th>Construct</th><th>Instrument</th><th>Class 1</th><th>Class 2</th><th>Class 3</th><th>Class 4</th><th>Class 5</th><th>Class 6</th></tr>
<tr><td>Team Effectiveness</td><td>GTA Rating of Team Effectiveness</td><td rowspan="2">17</td><td rowspan="2">22</td><td rowspan="2">23</td><td rowspan="2">24</td><td rowspan="2">21</td><td rowspan="2">19</td></tr>
<tr><td>Engineering Practice</td><td>Design, Programming, & Technical Writing Scores</td></tr>
</table>

Phase 1: Team Effectiveness, Quantitative Results

The summary of GTA ratings, aggregating the 5 performance indicator ratings (see Appendix C) at the team-level to create a team effectiveness score between 5 – 15 for each team, was used to create a three-level hierarchical categorization of the teams in terms of their effectiveness. A histogram of the entire data set (*N=126* teams aggregating all 6 cases) can be viewed in Figure 4-1.

Figure 4-1

Histogram of Team Effectiveness Ratings, entire cohort

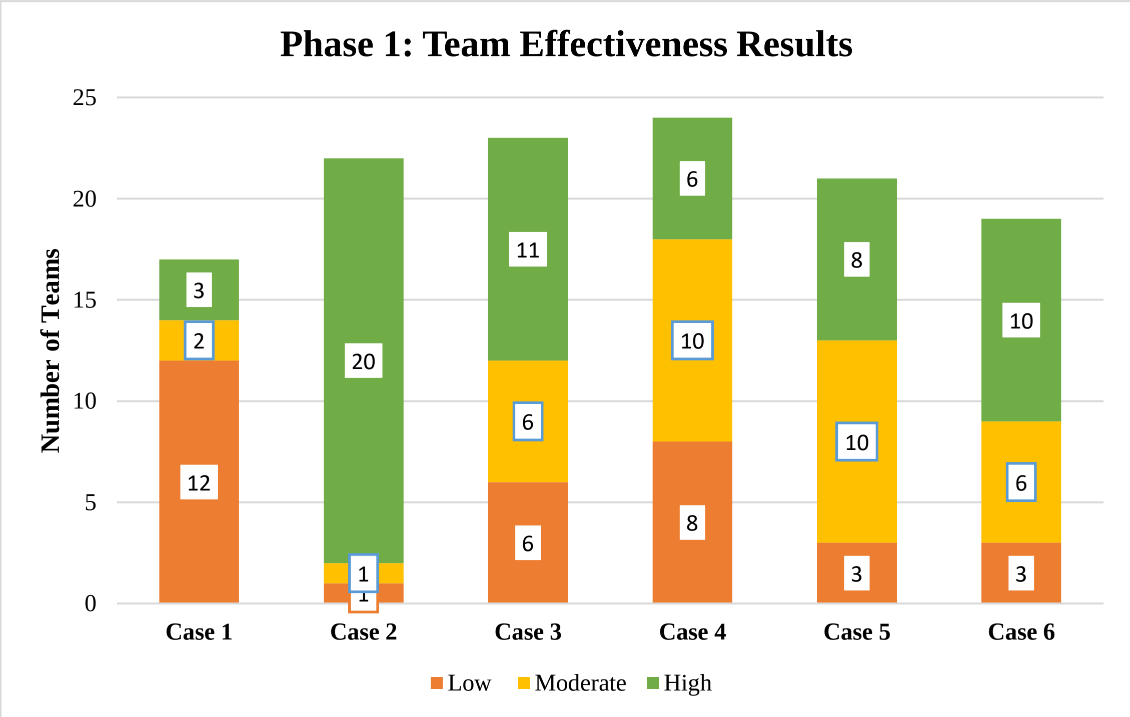


The median for the entire data set (*N=126*) of GTA ratings was 13 and the mean was 12.68 (2.399). The data were unimodal with a substantial ceiling effect, negatively skewed with more teams having higher ratings. Using the median of 13 as an initial cut point in order to create hierarchical categories within which to place each team, those above the median (GTA rating of 14 or 15) were established as being in the "high" team effectiveness category. Because the values lower than the median showed substantial spread, the median of this lower half (rating of 11) was set as the second cut point to separate this lower half into a "low" and a "moderate" team effectiveness category.

The GTA ratings of each team, within each case were coded with the identification as a low (5-11 aggregate GTA rating), moderate (12-13), and high (14-15) effective team. These rating categories for each case (class) can be found in figure 4-2.

Figure 4-2

Phase 1: Team Effectiveness Results, per case



Note. The values inside the stacked bars indicate the number of teams within the rating category, per case.

Across the 6 cases, case 2 had the smallest variation in team effectiveness with all but 2 teams receiving a high effective rating from their GTA. Case 1 has a noticeably greater percentage of low effective teams, based on their GTA ratings, while cases 3-6 all appear to be somewhat similar in their distribution of team effectiveness ratings.

Phase 1: Team Effectiveness, Qualitative Results

The GTA comments (see Appendix C) provided additional insight into the team dynamics that reflected team effectiveness categories in which each team was categorized (see Table 4-3). The low effective teams received comments from their GTAs that overwhelmingly included elements of overall team dysfunction. Among these dysfunctionalities were descriptions of teams consistently arguing, struggling with course concepts, absent team members, and time management issues that caused teams to fall behind in their progress to complete the project for the semester.

The moderately effective teams received GTA comments that described team dysfunction with some similar details as the low effective teams but added descriptions of teams addressing any challenges and approaching some cohesion through attempting to establish team member roles and getting along but lacking in ability to communicate consistently. Alternatively, the high effective teams received GTA comments that were focused on team's ability to adequately manage their time, efficiently work together, and clearly define team member roles. The spectrum from dysfunctional, low effective teams to cohesive, high effective teams was clearly observed in the thematic analysis of the GTA comments. A table of emergent themes and GTA comments by effectiveness category is available in Table 4-3.

Table 4-3

Team Effectiveness: Qualitative Themes and Quantitative Categories

Effectiveness Themes	Effectiveness Categories	Representative GTA comments
• Lack accountable interdependence • Lack mature communication • Unable to manage the purpose • Unable to resolve conflict • Issues with product conflict resolution • Minimal goal clarity • Minimal common purpose establishment	Low *(n=33)*	*"Did not handle long project well, completely didn't design a part until 20 minutes before the deadline"* *"Did not mesh well together"* *"Power struggle, did not work well together"* *"Team was consistently behind and never seemed to know what was going on"* *"Team member missed days of final project work; one teammate was extremely disengaged all semester"*
• Lack mature communication • Able to clarify goals and common purpose • Some issues with conflict resolution	Moderate *(n=35)*	*"Meshed well together, only worked in class"* *"Had teamwork issues in the middle of semester, was fine at the end and beginning"* *"Group worked well together but struggled to complete tasks"* *"Team had a leader that was controlling"*
• Fluid communication • Accountable interdependence of all team members • Exceptional role clarity for team members • Common purpose clear and understood by all team members	High *(n=58)*	*"Group was engaged and on task and had a good final project. I know there are some issues in distribution of tasks, but they overall were a good group"* *"This team was very capable and asked good questions"* *Great group, very efficient and capable. Did good work all semester"*

Phase 1: Engineering Practice

For each of the three features of engineering practice (i.e., design =0-60 points; programming=0-40 points; and technical writing=0-100 points; see Appendices D and E), descriptive summaries at the team-level were used to characterize the scores. Since each of the three features are scored based on points, to compare each of the features, three aggregate scores were calculated for each team. Table 4-4 shows the descriptive summary of each of the engineering practice scores for the entire set of six cases (126 teams) to establish a whole-group framework against which each individual team can be compared.

Table 4-4

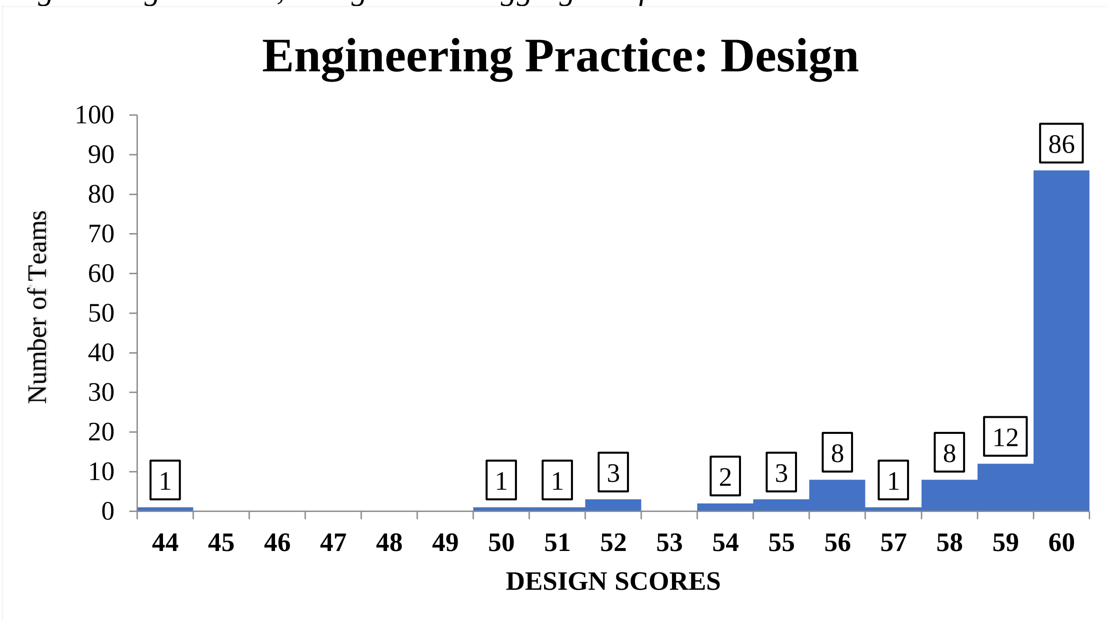
Engineering Practice Descriptive Statistics

Score	N	Minimum	Maximum	Mean	SD
Written	126	61.5	100	91.89	5.96
Design	126	44	60	58.82	2.5
Programming	126	10	40	34.87	6.72
Total	126	159.5	200	185.57	9.43

Histograms were generated (for each feature separately, as well as a combined 'engineering practice' score on 0–200-point scale) to observe frequency distribution characteristics. As with the team effectiveness ratings, before exploring these frequency distributions within a case (class), all 126 teams across all cases will first be aggregated to explore the whole-group distribution, against which individual teams or even class-aggregate teams can be compared in Phase 2 analyses. The aggregated, whole cohort, frequency distributions separately for each of the three engineering practice scores can be seen in Figures 4-3 to 4-5.

Figure 4-3

Engineering Practice, Design Scores aggregated for the entire cohort



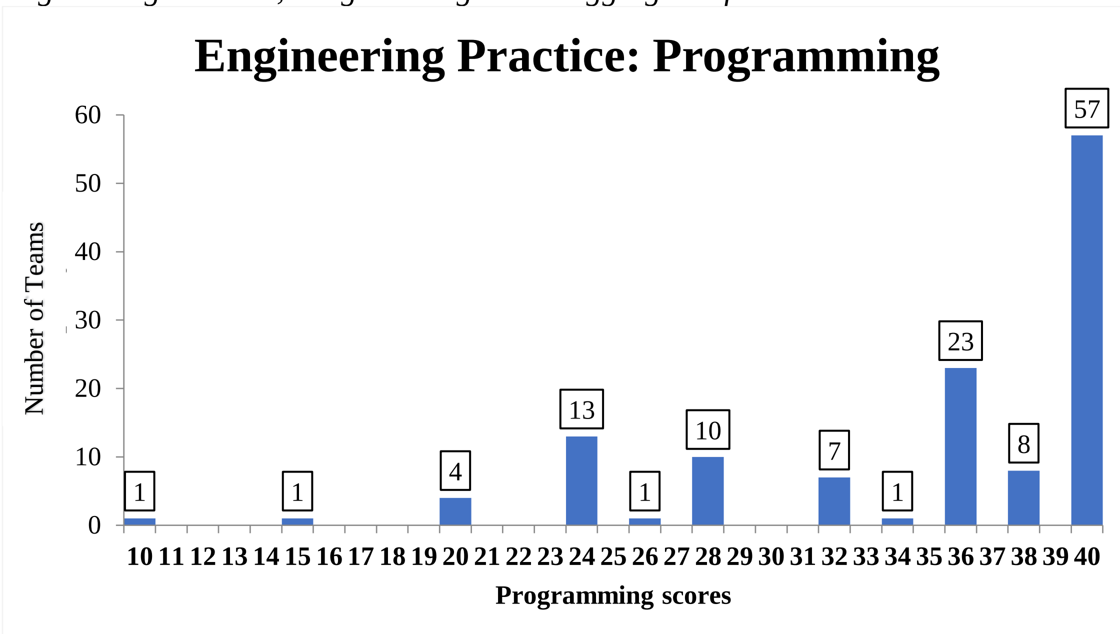
Note. The values above each bar indicate the number of teams that received the design score.

The final design score for each team is captures the quality of each team's iterative, engineering practice design efforts. Each case (class) had a final demonstration date in which the design of the capstone project was to be operational. Up to that point, teams were afforded the opportunity to iterate the design of their components to meet the specifications and functionality outlined in the rubric provided to each team in advance (see Appendix D). The distribution of design scores (Figure 4-3) displays that nearly every team received very high to perfect scores; this is likely due to the iterative nature of design and student teams iterating until they got their design 'right'.

Programming was the second score of the capstone project, totaling 40 points. The aggregate programming scores of each team across the cases is represented in the histogram, Figure 4-4.

Figure 4-4

Engineering Practice, Programming scores aggregated for the entire cohort



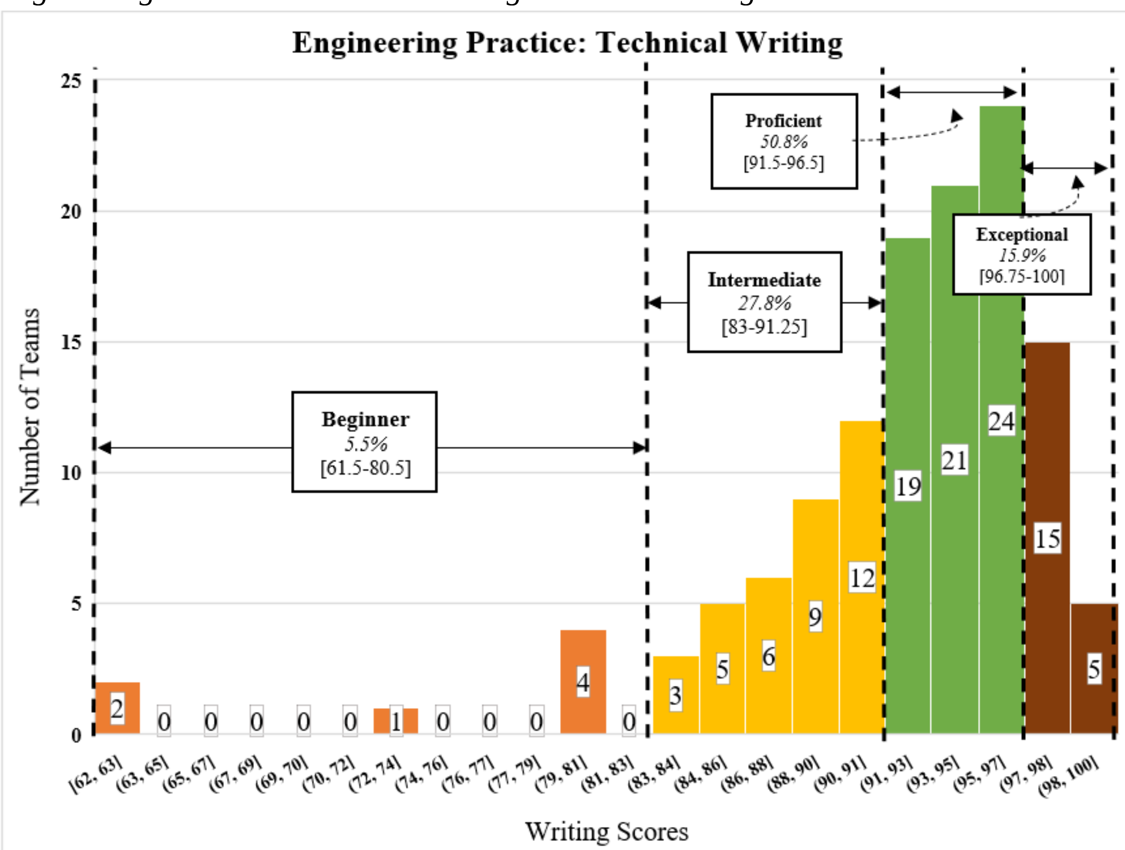
Note: The values above each bar represent the number of teams that received the programming score.

The programming score distribution is more varied than the design scores before. All teams were provided guided resources in writing the code that enabled the programmable logic controller to coordinate the displays and mechanical components. Teams also had in-class access to GTAs and faculty instructors for help and to ask questions. Programming is not as intuitive as design, which could be a reason for this distribution having more variability than design. The purpose of the engineering design course is to provide opportunities for students to bolster skills in resource utilization and critical thinking. A disadvantage to some teams could have stemmed from a lack of experience or prior knowledge in programming language translation. The computer language that all students learned in the prerequisite course was Python. The logic controllers required a different programming language, which necessitated students to take their Python knowledge and translate to the new language. Some teams had members with experience in multiple programming languages, while other teams were composed of members with only the experience of Python from the prerequisite course.

The third score of the capstone design project was the team's written technical report worth up to 100 points (see Appendix E). A histogram of the whole-cohort technical writing can be found in Figure 4-5. Teams whose scores are at the right-hand boundary of each bar's 2-point score range is included within that bar's frequency count. Each category label includes the cumulative percent of each category and the actual engineering practice score range in square brackets.

Figure 4-5

Engineering Practice: Technical Writing Scores and Categorization



Note: The values above each bar represent the number of teams that received a technical writing score within the range of technical writing scores.

The technical writing histogram is even more distributed than the two prior engineering practice feature scores. Like the previous two engineering practice features, the technical writing involved a series of iterative steps which built in GTA feedback. Differing from the previous two engineering practice features, the iterative, feedback loop was a required step to the final technical writing score. Student teams had two deadlines in which the teams were required to submit their in-progress, technical writing document for GTA review and feedback. This requirement necessitated out-of-class coordination and communication of student teams to meet the multiple deadlines, plus there was no allotment of time in class for teams to work solely on their technical writing. Therefore, the technical writing score has the greatest potential of the three engineering practice features to indicate team effectiveness due to the necessity of consistent team cohesion and teamwork to meet the multiple submission deadlines.

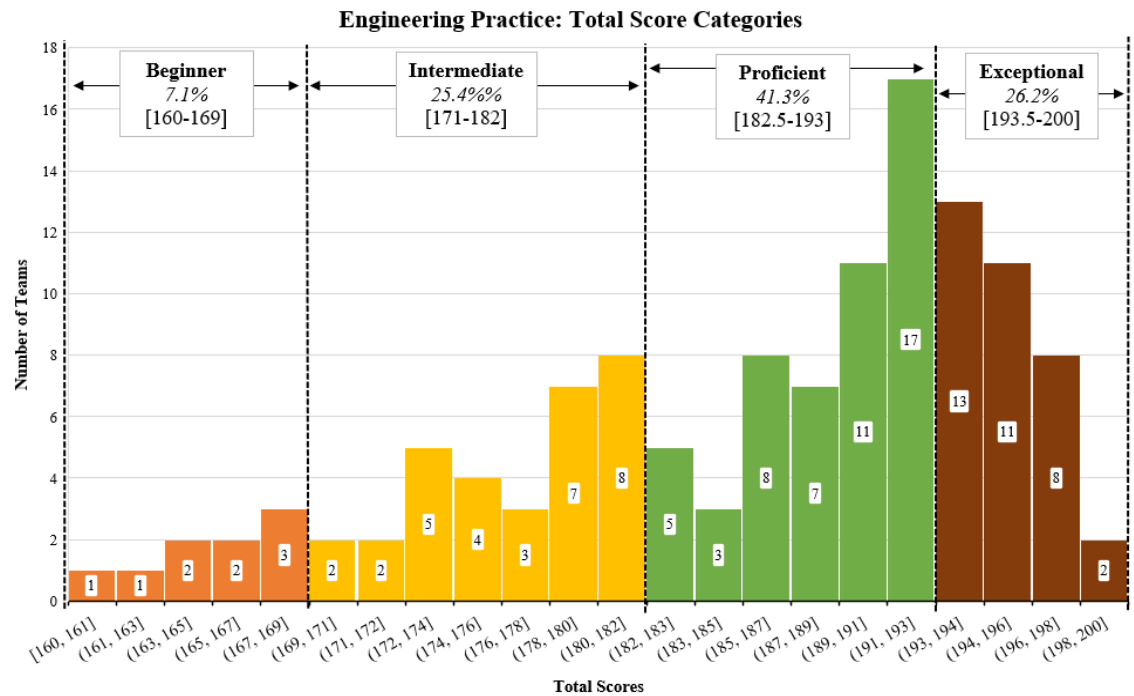
For these reasons, the technical writing score distribution was used to create engineering practice (technical writing) categories. The writing scores had a mean(SD) of *91.89(59.6)*, and a median at *93.5*. The creation of categories from these data was done in a qualitative manner. The data demonstrated a somewhat group-stratified distribution with 3 cut point opportunities with a relatively large difference in number of teams between one range and the next. Since the locations of the large relative frequency differences in adjacent ranges indicated by the dotted lines in Figure 4-5 could be interpreted as a relatively sparse score domain in comparison to the number of teams represented by the bars on either side, these proportionally sparse domains could be interpreted as a signifier for discriminating between distinctly different team performances on either side of that boundary. This is a similar logic to how Tretter et al.

(2006) interpreted sparse domains as signifiers of conceptual boundary cut points. Using these frequency differentials as cut points to establish boundaries between one category of performance from another, four categories of team's engineering practice, technical writing were established. From the highest total score category to the lowest total score, the Figure 4-5 categories are *exceptional, proficient, intermediate, and beginner*. Including these technical writing scores as separate categories will provide for follow-up analysis on phase 2.

A final aggregate score of all three engineering practice feature scores created a total engineering practice score for each team. The distribution of total engineering practice scores can be viewed in the Figure 4-6. Teams whose scores are at the right-hand boundary of each bar's 2-point score range is included within that bar's frequency count. Each category label includes the cumulative percent of each category and the actual engineering practice score range in square brackets.

Figure 4-6

Total Engineering Practice Scores and Categories



Note. Values within each bar represent the number of teams included in each score range bin. A square bracket indicated the inclusion of the score within the bin, a parenthesis indicates the numerical score carries into the next bin.

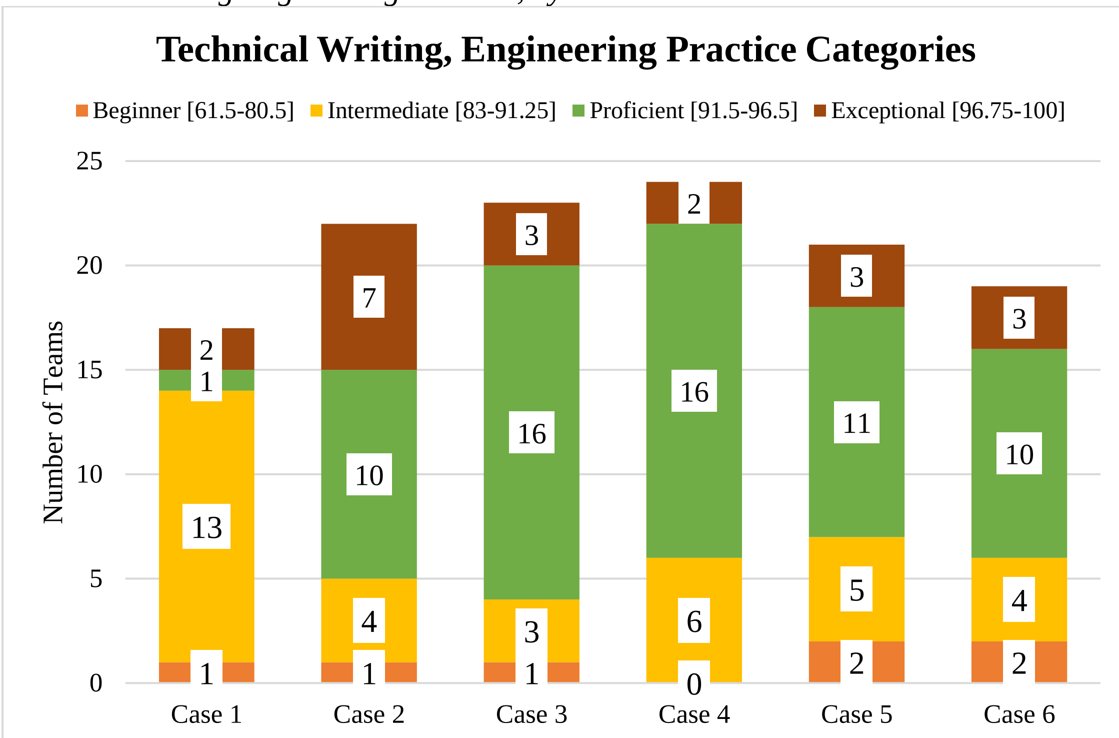
The total engineering practice scores had a mean(SD) of *185.57(9.43)* and a median at *188.25*. The data, like that of the technical writing scores in Figure 4-5, demonstrated a somewhat group-stratified distribution with 3 peaks each followed by a drop-off in the bar with the next higher score range. Using the same logic as before with Figure 4-5, the drops represented by the drop-offs after each of the 3 peaks in Figure 4-6 could be interpreted as a relatively sparse score domain in comparison to the number of teams represented by the taller peaks immediately preceding. These proportionally sparse domains could be interpreted as a signifier for discriminating between distinctly different team performances on either side of that boundary. Using these peaks as cut points to establish boundaries between one category of performance from another, four categories of team's total engineering practice were established. From the highest total score category to the lowest total score, the Figure 4-6 categories are *exceptional, proficient, intermediate, and beginner*.

The definition of engineering practice is not simply a problem-solving process and specialized knowledge (Sheppard et al., 2007). Rather, engineering practice is also complex, thoughtful, and intentional integration of competency toward a meaningful end. Demonstration of engineering practice, therefore, can be thought of as an engineering competency and the category labels used to describe the groups of teams in each category depict a descriptive level of competency displayed by those teams.

Using the categories established by Figure 4-5 and 4-6 for the entire cohort, the results of the technical writing performance – which showed the most variability - and total engineering practice performance categorization separately for each case can be seen in Figure 4-7 and 4-8, respectively. The color legend includes the engineering practice score range for each category, for reference.

Figure 4-7

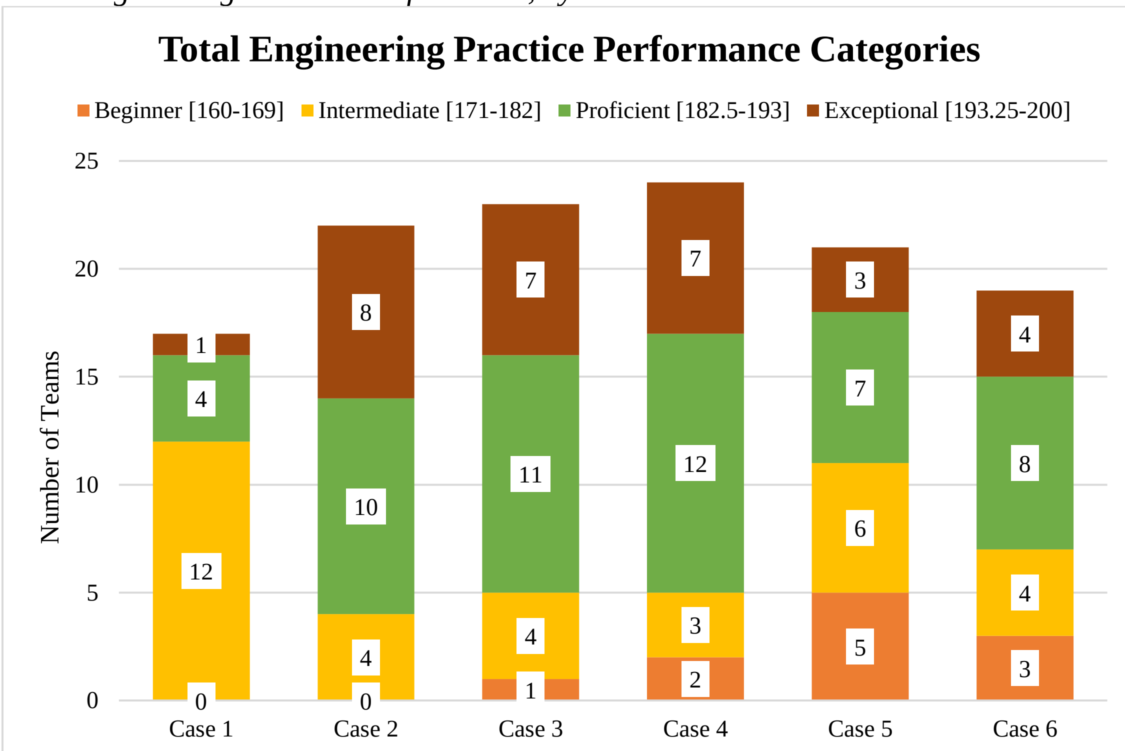
Technical Writing Engineering Practice, by case



Case 1 had a disproportionate number of intermediate teams in comparison to the rest of the cases having mostly proficient. All cases, but case 1, consisted of mostly proficient or better teams. The number of beginner teams were consistently low in all cases.

Figure 4-8

Total Engineering Practice Performance, by case



Cases 2, 3, and 4 consisted of mostly proficient or better teams, with Case 1 having a disproportionate number of intermediate teams in comparison with the rest of the cases. More beginner teams appeared in Case 5 which also had proportionally more intermediate teams compared to all other cases except Case 1.

Box plots for each case were generated to explore the location of any extreme outliers in team's engineering practice total. Figure 4-9 shows the spread of engineering practice scores, within each case.

Figure 4-9

Engineering Practice boxplot of total scores, within case

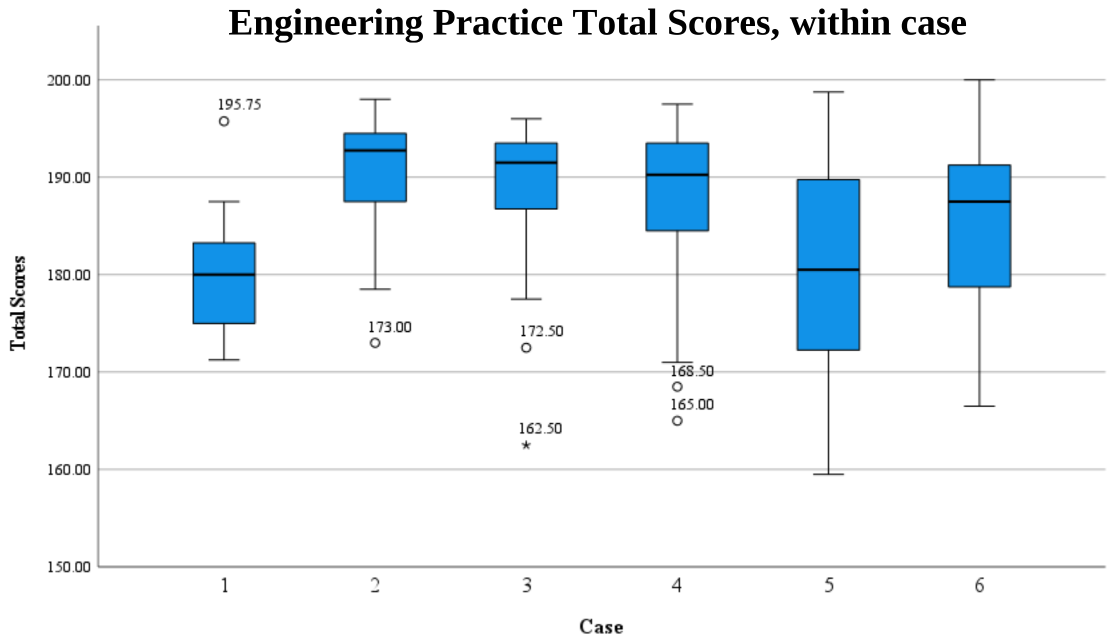


Figure 4-9 shows case 5 had the widest dispersion of total scores and several cases (Case 2, 3, and 4) demonstrated a ceiling effect toward the higher scores. Since many of the cases were skewed toward the higher total scores it was expected that there would be some teams with relatively extreme high or low total scores; a postulation confirmed by the outliers on the lower score range in cases 2-4 and case 1 with an outlier on the high end of the score range.

Phase 1: Teamwork Perceptions, Individual-level Unit of Analysis

Teamwork perceptions were measured at the individual (student)-level using two instruments: (1) ***Teamwork Perceptions Survey*** (see Appendix A) and (2) ***Peer Evaluations of Team Member Effectiveness (PETME)*** (see Appendix B)**.** The teamwork perceptions survey consisted of two measures: a 9-item collective efficacy scale and a forced ranking of 6 effective team characteristics. The PETME contained 4-items in which students evaluated their teammates effectiveness using behaviorally anchored ratings. All teamwork perceptions measures were collected at three timepoints (See Table 3-2) with varying response rates on each measure. The teamwork perceptions results presented in this section will summarize response rates for each instrument, at each relevant timepoint, first. Then, the results of the analysis of each instrument will be presented.

Teamwork Perceptions Survey: Response Rates

The individual (student)-level measure of teamwork *perceptions*, using the teamwork perceptions survey instrument varied in response rates at each of the three time-points of data collection. Table 4-5 shows the individual-level student response rates, per case, for each timepoint.

Table 4-5

Teamwork ***Perceptions*** *Survey response rate, individual-level unit of analysis*

		Timepoint 1		**Timepoint 2**		**Timepoint 3**	
	Students enrolled	*# of Responses*	*Response (%)*	*# of Responses*	*Response (%)*	*# of Responses*	*Response (%)*
Class 1	66	68	103%	68	103%	39	59%
Class 2	86	84	98%	81	94%	69	80%
Class 3	90	86	96%	81	90%	65	72%
Class 4	92	90	98%	85	92%	49	53%
Class 5	82	79	96%	70	85%	46	56%
Class 6	72	68	94%	65	90%	40	56%
Total	488	475	97.3%	450	92.2%	308	63.1%

As is shown in Table 4-5, response rates were strong at timepoint 1 and 2, and moderate response rate at timepoint 3. The unusual 103% for Class 1 at timepoint 1 and 2 is likely due to a mistaken double entry of responses during the administration of the survey. Timepoint 3 represents the end of the semester, presenting a possible reason for why the response rate percentages drop at this timepoint.

Teamwork Perceptions Survey: Instrument Reliability and Validity

Using SPSS Statistics version 27, an exploratory factor analysis (FA) of the Student Teamwork Perceptions Survey (Appendix A, Part 1) was conducted using principal component analysis (PCA). The PCA was used as a data reduction strategy and confirmatory validation of the 9-item collective efficacy scale, first validated by Lent et al. (2006). The PCA used oblique rotation (Promax) on 9 items on the timepoint 1, pre-survey (*n=476*), allowing factors to be correlated. A Cronbach's alpha of 0.96 was obtained for the pre-survey overall, which indicated the items grouped into one overall factor for this sample of students. As expected, the 9-items of part #1 (see Appendix A, #1, a-i) demonstrated a high level of internal consistency (Cronbach, 1951). At each of the three timepoints the scale was administered (see Table 3-2), the 9-items (a-i) had Cronbach's alphas of 0.96 (timepoint 1), 0.91 (timepoint 2), and 0.97 (timepoint 3).

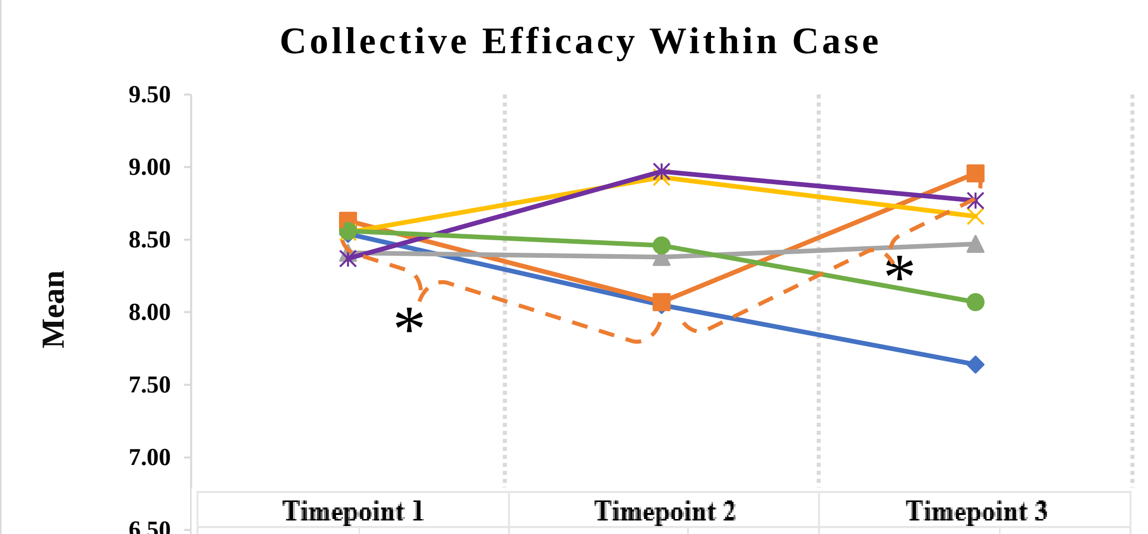
The PCA was used to confirm validity of the 9-item scale that measured collective efficacy. Inspection of the correlation matrix, at each timepoint, showed that all items had at least one correlation greater than the recommended 0.3; most correlation coefficients ranged from 0.5 to 0.8, indicating all items contributed substantially to measuring the same construct of collective efficacy. The overall Kaiser-Meyer-Olkin (KMO) was 0.956, 0.947, and 0.951, for timepoints 1, 2, and 3, respectively. All KMO measures greater than or equal to 0.9 is "marvelous" on Kaiser's (1974, p. 35) classification of measure values, which indicates a linear relationship between the items and sampling adequacy. Based on these results, the decision was made to retain and aggregate into one mean score all 9 items of the collective efficacy scale.

Teamwork Perceptions: Collective Efficacy

Collective efficacy means and standard deviations were calculated for each case, at each timepoint (see Figure 4-10).

Figure 4-10

Collective Efficacy Results for each case at each timepoint



	Timepoint 1		Timepoint 2		Timepoint 3	
	M	SD	M	SD	M	SD
Case 1	8.54	1.29	8.05	2.20	7.64	1.92
Case 2	8.63	1.32	8.07*	1.17	8.96*	1.39
Case 3	8.41	1.36	8.38	1.73	8.47	1.74
Case 4	8.55	1.04	8.93	0.85	8.66	1.23
Case 5	8.37	1.56	8.97	1.24	8.77	1.52
Case 6	8.56	1.30	8.46	1.29	8.07	2.29

Note. * indicates statistically different mean for that case at that timepoint compared to the same-case prior timepoint.

At timepoint 1, all cases have very similar average collective efficacy. At timepoint 2, cases began to diverge with cases 4 and 5 slightly increasing from timepoint 1; while cases 1, 2, 3, and 6 decreased in average collective efficacy, but case 2 was the only statistically significant decrease between timepoints 1 and 2. From timepoint 2 to 3, cases 1, 4, 5, and 6 decreased while case 3 slightly increased, and case 2 was the only statistically significant increase. A similar slope pattern was noticed with cases 4 and 5. Case 3 has the least noticeable change of means across the three timepoints. From timepoint 1 to 3 cases 2, 3, 4, and 5 demonstrated a slight rise of collective efficacy while the remaining cases (1 and 6) posted a decrease.

A repeated-measures, one-way ANOVA was conducted within each case to determine whether there was a statistically significant difference in collective efficacy means across the three timepoints, within a case. Preliminary analysis found each case met the acceptable range of normality and outliers as assessed by boxplot and Shapiro-Wilk test ($p>.05$), respectively. The assumption of sphericity was assessed by Mauchly's test of sphericity ($p>.05$), for cases where sphericity assumption was violated (case 6) a Greenhouse-Geisser correction was applied. A statistically significant difference was found for case 2, $F(2, 136)=9.26, p<.001, \eta^2=0.12$. A post hoc analysis with a Bonferroni adjustment revealed statistically significant decrease for case 2 from timepoint 1 *(M=8.63, SD=1.32)* to timepoint 2 *(M=8.07, SD=1.17)* and a significant increase from timepoint 2 *(M=8.07, SD=1.17)* to timepoint 3 *(M=8.96, SD=1.39)*.

The repeated measures ANOVA results and post hoc results for statistically significant collective efficacy mean differences in timepoints are reported in Table 4-6.

Table 4-6

Collective Efficacy ANOVA Results with pairwise timepoint comparison

	ANOVA	Timepoints	Mean difference	95% CI for difference
Case 1	$F(2, 76)=2.86, p=0.063$			
Case 2*	$F(2, 136)=9.26$, $\mathbf{p<.001, \eta^2=0.12}$	1 → 2 2 → 3	0.56, **p=.026** .887, **p<.001**	[.052, 1.063] [-1.343, -.432]
Case 3	$F(2, 128)=.05, p=0.952$			
Case 4	$F(2, 96)=1.08, p=0.182$			
Case 5	$F(2, 90)=1.96, p=0.147$			
Case 6	^$F(1.52, 59.17)=1.15, p=.322$			

Note. * *indicates SIG.* ^ *indicates sphericity violation and Greenhouse-Geisser correction.*

The effect size, reported by eta squared (η^2) of case 2 provides insight into the magnitude of the differences between the collective efficacy means at the timepoints. In case 2, $\eta^2=0.12$, which is a moderate effect size according to Cohen (1988), representing 12% of the variance accounted for by timepoint. This suggests that collectively, the individual students in Case 2 may have had meaningfully lower judgements of their team's efficacy at timepoint 2 compared to timepoints 1 or 3.

Teamwork Perceptions: Effective Team Member Characteristics

The teamwork perceptions survey (see Appendix A, part 2) requested each student to rank 6-**effective team characteristics** at each of the three data collection timepoints. The six effective team characteristics rank ordered by students was: (a) communicating clearly, (b) establishing a common purpose/goal(s), (c) ability to resolve conflict, (d) accountable individuals (i.e., every person does what they say they will), (e) every individual has clearly defined roles/tasks, and (f) every individual is supported and confident in sharing their own ideas. The forced ranking order was (1) most important to (6) least important with the numbers between indicating the order of perceived importance to the student in terms of effective team characteristics. The results of the individual (student)-level rankings, across the entire cohort, are presented first from the perspective of timepoints to establish an interpretation baseline. Then, the frequency results of the entire cohort, across timepoints are aggregated for a characteristic perspective. As a verification of baseline interpretation, a within cases independence test will determine if the aggregate rankings for each characteristic were equally or nonequally distributed across all importance levels (1-6).

Effective Team Member Characteristics: Timepoint Perspective. The results of the ranked effective team characteristics are presented first by aggregating across the entire cohort, within each timepoint of data collection, to establish a baseline for interpretation. Frequency totals and proportions, per rank within each characteristic (a-f), from student responses at timepoints 1, 2, and 3 are presented in tables 4-7, 4-8, and 4-9, respectively. The highest proportions within each characteristic have been bolded to facilitate identifying any potential patterns of which characteristics were judged to be most or least important.

Table 4-7

Team member characteristic perceptions, entire cohort at ***timepoint 1*** *(n=469)*

Rank (1=most important)	**Characteristic Frequency (proportion)**					
	a	**b**	**c**	**d**	**e**	**f**
1	***227 (.48)***	*76 (.16)*	*10 (.02)*	***126 (.27)***	*14 (.03)*	*16 (.03)*
2	***130 (.28)***	***102 (.22)***	*47 (.10)*	***113 (.24)***	*44 (.09)*	*33 (.07)*
3	*59 (.13)*	***109 (.23)***	*87 (.19)*	*79 (.17)*	*83 (.18)*	*52 (.11)*
4	*32 (.07)*	*98 (.21)*	***114 (.24)***	*73 (.16)*	*81 (.17)*	*71 (.15)*
5	*19 (.04)*	*57 (.12)*	***133 (.28)***	*54 (.12)*	***100 (.21)***	***106 (.23)***
6	*2 (.004)*	*27 (.06)*	*78 (.17)*	*24 (.05)*	***147 (.31)***	***191 (.41)***

At timepoint 1, characteristic (a)-communicating clearly garnered the highest proportion of (1)-most important rankings, while characteristic (f)-every individual is supported and confident in sharing their own ideas, had the highest proportion of students ranking (6)-least important. Characteristic (e)-every individual has clearly defined roles/tasks also received rankings indicating it to be less important to students, while (b) establishing common purpose and (d) accountably of individuals doing what they say they will, were ranked higher in proportion with communicating clearly. Characteristic (c)-ability to resolve conflict, was near the middle of the rankings.

Table 4-8

*Team member characteristic perceptions, entire cohort at **timepoint 2** (n=446)*

Rank (1=most important)	**Characteristic Frequency (proportion)**					
	a	**b**	**c**	**d**	**e**	**f**
1	***211 (.47)***	*70 (.15)*	*30 (.06)*	*73 (.16)*	*6 (.01)*	*11 (.03)*
2	***113 (.24)***	***120 (.25)***	*58 (.13)*	*74 (.17)*	*33 (.07)*	*29 (.06)*
3	*64 (.14)*	***96 (.20)***	***100 (.22)***	***89 (.20)***	*51 (.11)*	*43 (.10)*
4	*39 (.08)*	*84 (.18)*	***117 (.26)***	***100 (.22)***	*61 (.14)*	*53 (.12)*
5	*14 (.03)*	*50 (.11)*	***102 (.23)***	*69 (.16)*	***140 (.31)***	***93 (.21)***
6	*5 (.01)*	*26 (.05)*	*39 (.09)*	*41 (.09)*	***155 (.35)***	***217 (.49)***

Timepoint 2 trended similarly to timepoint 1, with characteristic (a)-communicating clearly ranking "most important" and characteristic (f)-every individual is supported and confident in sharing their own ideas, as "least important". Characteristic (e)-pertaining to clearly defined roles/tasks of individuals shifted toward less important than timepoint 1; the remaining characteristics (b-d) remained relatively consistent in comparison to timepoint 1.

Table 4-9

*Team member characteristic perceptions, entire cohort at **timepoint 3** (n=314)*

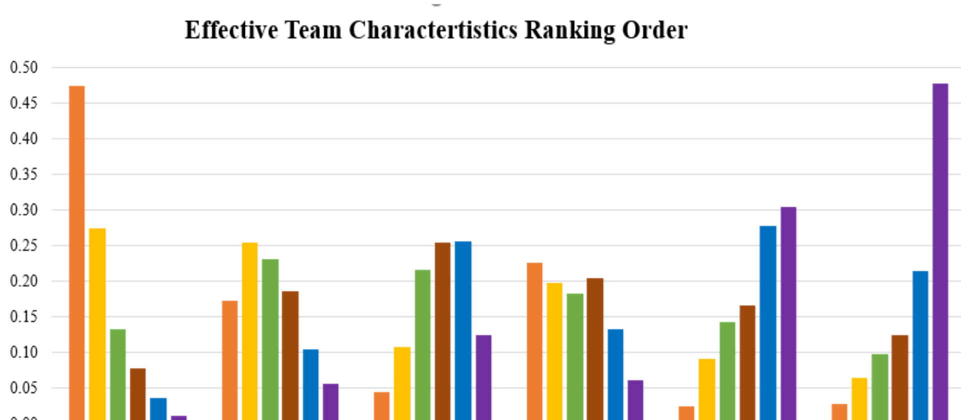
Rank (1=most important)	**Characteristic Frequency (proportion)**					
	a	**b**	**c**	**d**	**e**	**f**
1	***144 (.46)***	*65 (.21)*	*14 (.05)*	***78 (.25)***	*8 (.03)*	*5 (.02)*
2	***93 (.30)***	***90 (.29)***	*27 (.09)*	*55 (.18)*	*34 (.11)*	*15 (.05)*
3	*38 (.12)*	***78 (.25)***	***78 (.25)***	*56 (.18)*	*40 (.13)*	*24 (.08)*
4	*23 (.08)*	*45 (.14)*	***81 (.26)***	***77 (.25)***	*60 (.19)*	*28 (.09)*
5	*11 (.04)*	*21 (.07)*	***79 (.25)***	*39 (.12)*	***100 (.32)***	***64 (.20)***
6	*5 (.02)*	*15 (.05)*	*35 (.11)*	*9 (.03)*	***72 (.23)***	***178 (.57)***

Timepoint 3 did not change much in proportion from the two prior timepoints. Characteristic (a)-communicating clearly remained the most important overall; while characteristic (f)-every individual is supported and confident in sharing their own ideas remained the least important, overall.

Effective Team Member Characteristics: Characteristic Perspective. A consistent pattern was observed in the proportions of rankings for each characteristic, at each timepoint, for the entire cohort. Because of the similar ranking pattern at all three timepoints, aggregating importance rankings across all 3 timepoints strengthens the statistical stability due to more data points without losing any nonexistent differential nuance per timepoint. Thus, subsequent characteristic ranking analysis will aggregate responses across all three timepoints. To establish an interpretation baseline, the frequencies for each ranking order, across the three timepoints were aggregated and the proportion of rankings within each characteristic is represented graphically in Figure 4-11.

Figure 4-11

Effective Team Characteristic Rankings, entire cohort for all timepoints



	(a) Communicating Clearly	(b) Establishing common purpose	(c) Ability to resolve conflict	(d) Accountability of individuals	(e) Every individual has clearly defined roles/tasks	(f) Every individual is supported and confident in sharing their own ideas
1 Most Important	0.47	0.17	0.04	0.23	0.02	0.03
2	0.27	0.25	0.11	0.20	0.09	0.06
3	0.13	0.23	0.22	0.18	0.14	0.10
4	0.08	0.18	0.25	0.20	0.16	0.12
5	0.04	0.10	0.26	0.13	0.28	0.21
6 Least Important	0.01	0.06	0.12	0.06	0.30	0.48

1st: Team Communications	2nd: Team Accountability	3rd: Individuality

Characteristics (a) clear Communication and (b) establishing a common purpose emerged as the two most important effective team characteristics based on the proportional ranking order of the entire cohort. The two of least importance in the overall ranking of characteristics was (f) every individual being supported and confident in their ideas and (e) every individual having clearly defined roles/tasks. The middle rankings converged around the ability to resolve conflict (c) and accountability of individuals doing what they say they will (d).

The red boxes in figure 4-11 show a grouping of the highest proportions for each characteristic. The six specific characteristics can be grouped into three overall themes, two per theme, based on relative importance as judged by the students. Of most importance, as reported by the entire cohort, were characteristics (a) and (b) which both are team focused communication characteristics and can be grouped into a thematic label *Team Communications* (see Figure 4-10). Characteristics (c) and (d) both fall into the middle range of importance and are both characteristics that connect to *Team Accountability*. Least important, as reported by the entire cohort, were characteristics (e) and (f) which both are related to aspects focused on the individual member rather than the team.

Effective Team Characteristics: Distribution of Rankings Within Case. A chi-square test of independence was conducted for each case, aggregating all timepoints, between the rankings and the effectiveness characteristics. This chi-square analysis will statistically test if the aggregate rankings for each characteristic were equally distributed across all importance levels 1-6 or nonequally distributed. Tables 4-10 show the results of this analysis, indicating significance (nonequal distribution) and magnitude of association (Cohen, 1988).

Table 4-10

Effective Team Characteristic within case chi-square

Case	Pearson chi-square	Magnitude of Association
1	$\chi^2(25) = 459.54$, $p < .001$	*Cramer's V=0.308*
2	$\chi^2(25) = 1321.51$, $p < .001$	*Cramer's V=0.371*
3	$\chi^2(25) = 752.64$, $p < .001$	*Cramer's V=0.329*
4	$\chi^2(25) =844.77$, $p < .001$	*Cramer's V=0.354*
5	$\chi^2(25) = 547.80$, $p < .001$	*Cramer's V=0.308*
6	$\chi^2(25) = 434.71$, $p < .001$	*Cramer's V=0.288*

Note. Cohen (1988) suggests V>.39 is moderate and V<.34 is weak.

Case 6 had the weakest association with a Cramer's V=0.288; other cases showing association magnitudes nearer the boundary between weak and moderate. The standardized adjusted residuals, within each case, confirmed the pattern of the most to least important from the ordered rankings of characteristics. All residuals well above the standard errors of 2-3 (Agresti, 2013) were located in the cells showing that characteristics a and b were substantially more often ranked as high importance and characteristics e and f were substantially ranked as lesser importance.

Teamwork Perceptions: Peer Evaluations of Team Member Effectiveness (PETME)

A third measure of perceptions of teamwork were peer evaluations of team member effectiveness (PETME; see Appendix B). These perceptions were collected at three timepoints in the semester. Students submitted evaluations of teammates on 4-items using the 1-5 behavioral team member effectiveness ranking scale. Ratings for each person on a 4-member team were averaged from that person's 3 team members' evaluations of their teammate, which produced an individual-level teammate evaluation between a minimum average of 1 and a maximum of 5 for each person. A discrepancy range for each team was calculated at each timepoint, using the individual-level teammate evaluations of their peers. A team's discrepancy range represents the team-level score between the highest teammate evaluation average and the lowest teammate evaluation average. For example, in a team of 4 students, one of the four may have received an overall (low) evaluation average from their 3 peers with an average of 1.2 across all four items rated by all three teammates, whereas the highest-rated member of that same team may have received from their 3 peers an overall (high) evaluation average of 4.6 on the 5-point scale. This example would result in a team discrepancy score of 4.6 – 1.2 = 3.4 (a fairly high discrepancy). A higher discrepancy range at the team-level represents a substantial discrepancy of peers' evaluations of each other's contributions to the team; alternatively, a lower discrepancy range indicates a perception that all team members contributed approximately equally to the team's success.

PETME Response Rate. The peer assessment of team member contributions was a required submission of all students enrolled in the course. The response rates for each case, due to this requirement, were high overall. During the analysis of peer evaluations, it was determined that teams of four were omitted from the analysis when at least two individual team member peer evaluations were missing. This avoids situations of potential overreliance on possible outlier evaluations since it omits situations where a person's peer evaluation would be dependent on only 1 person's judgement, rather than an average of 2 or 3 peers. Teams of three (which were a small number) were omitted when at least one individual team member peer evaluation was missing for the same reason. The team-level response rate, at each timepoint, for the PETME instrument are in Table 4-11.

Table 4-11

Peer Evaluation of Team Member Effectiveness, team-level response rate

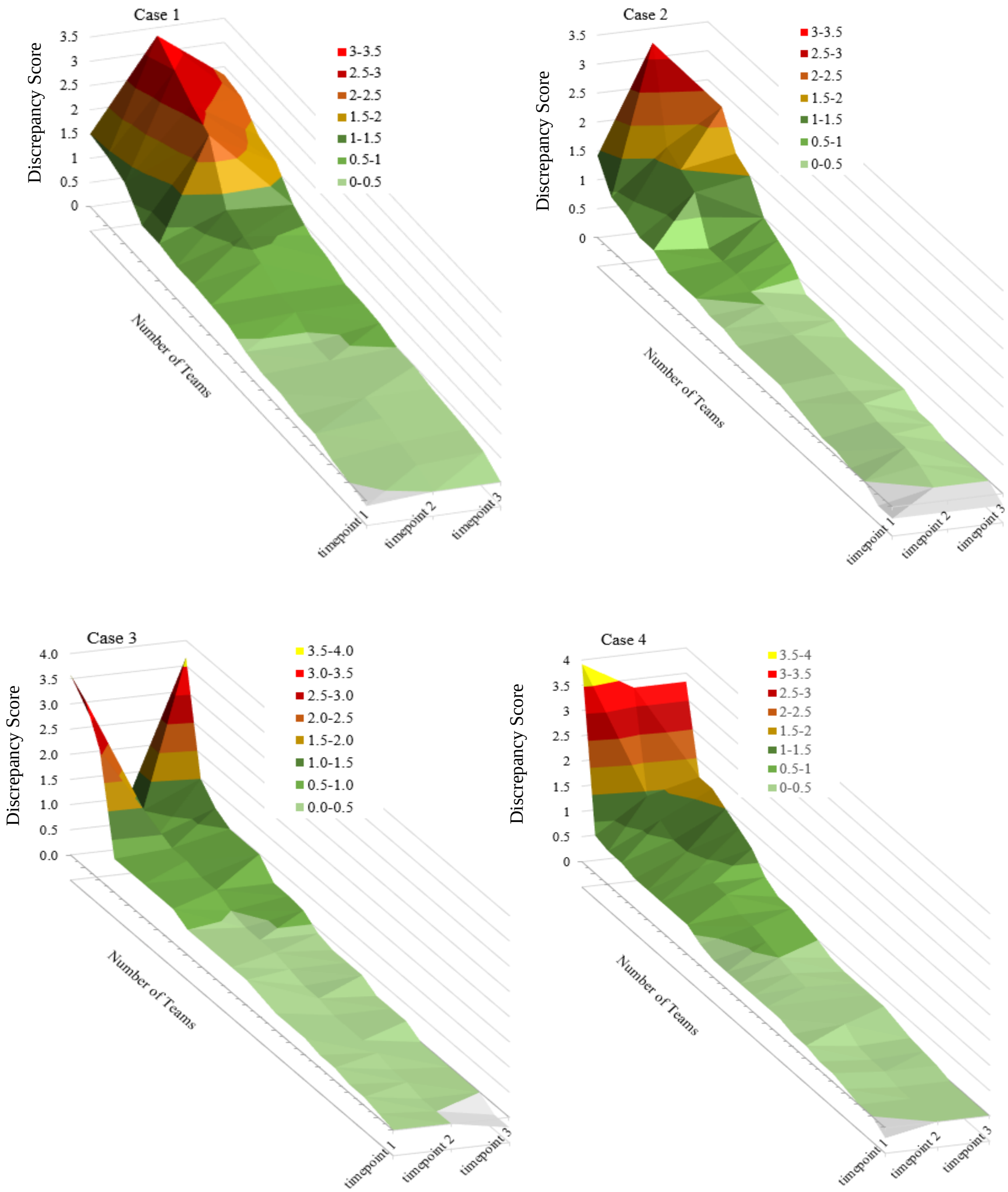
		Timepoint 1		**Timepoint 2**		**Timepoint 3**	
	# of teams	*# of teams omitted*	*Response (%)*	*# of teams omitted*	*Response (%)*	*# of teams omitted*	*Response (%)*
Case 1	17	1	94.1%	0	100%	0	100%
Case 2	22	1	94.1	1	94.1%	1	95.5%
Case 3	23	0	100%	0	100%	2	91.3%
Case 4	24	1	94.1%	0	100%	0	100%
Case 5	21	5	70.6%	1	95.2%	2	90.5%
Case 6	19	4	76.5%	1	94.7%	2	89.5%

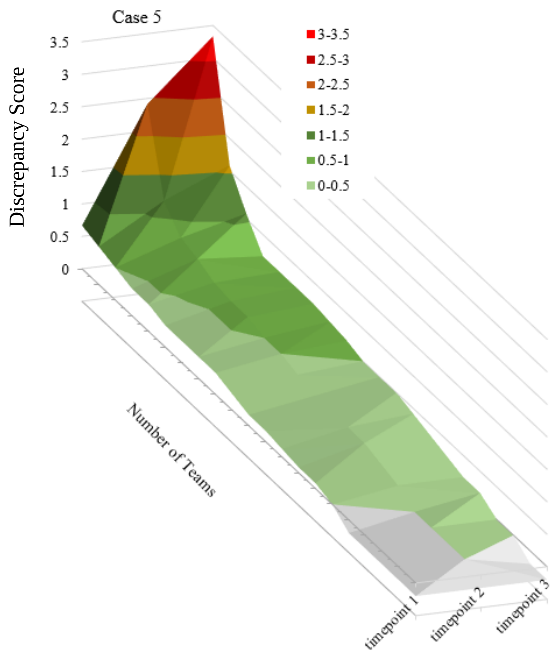
Case 5 and 6, at timepoint 1, had the most teams omitted in comparison to the rest of the cases and timepoints.

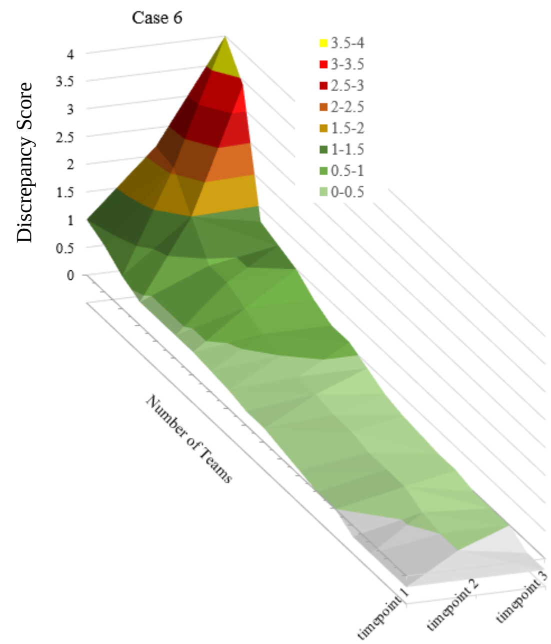
Team-level Discrepancies Within Case. Team-level discrepancy scores were sorted in descending order and are graphically represented in Figure 4-12. The 3-dimensional surface graphs are best conceptualized by taking a perspective imagining a viewpoint from the front, y-axis plane where the data collection timepoints are labeled. The graphs show how the number of teams at various levels of discrepancy ranges fluctuate across timepoints. Thus, when there are a relatively large number of teams with substantial discrepancies (e.g., in Figure 4-12 for Case 1 at timepoint 2 with 6 teams showing a discrepancy rating over 2.0) the graph shows a relatively long stretch of high discrepancies. By contrast, Case 3 at timepoint 3 shows only 1 team with a discrepancy over 2.0 before dropping down to discrepancies of 1.0 and below for all other teams in this case at timepoint 3. And for Case 3 at timepoint 2, there are no teams with a discrepancy higher than 1.0 (the deep valley at timepoint 2). The teams omitted at each timepoint are represented as missing data by the front, grey portion of the graph.

Figure 4-12

Descending Discrepancy Ranges, per case across timepoints







The highest discrepant team was in Case 6 at timepoint 3 with a range of 4. The next high discrepancy range was 3.92 at timepoint 1 in Case 4. The team in Case 4 with the high discrepancy at timepoint 1 recovered to a much lower discrepancy at timepoints 2 and 3 because the lowest evaluated team member left the class after timepoint 1 data was collected and before timepoint 2. The specific high-discrepant team in Case 6 at timepoint 3 was originally under a discrepant range of 1 for the first two timepoints, and a single team member caused the large uptick in peer evaluation discrepancy at timepoint 3.

As an overall trend, discussed further in Phase 3 of results during cross-case analysis, most teams in all cases had relatively low (<1.0) discrepancies for all timepoints, with Case 1 showing substantially more high-discrepant teams overall, compared to other cases. Another general trend observable in Figure 4-12 is at timepoint 3, when compared to timepoints 1 and 2, most cases had more teams shifting into moderate discrepancy levels (between 1.0 and 2.0; the dark green and orange color codes).

Phase 2: Cross-Construct, Within Case

This second phase presents the results of explored interactions across the three constructs of this study: team effectiveness, engineering practice, and teamwork perceptions to identify patterns and relationships within each case.

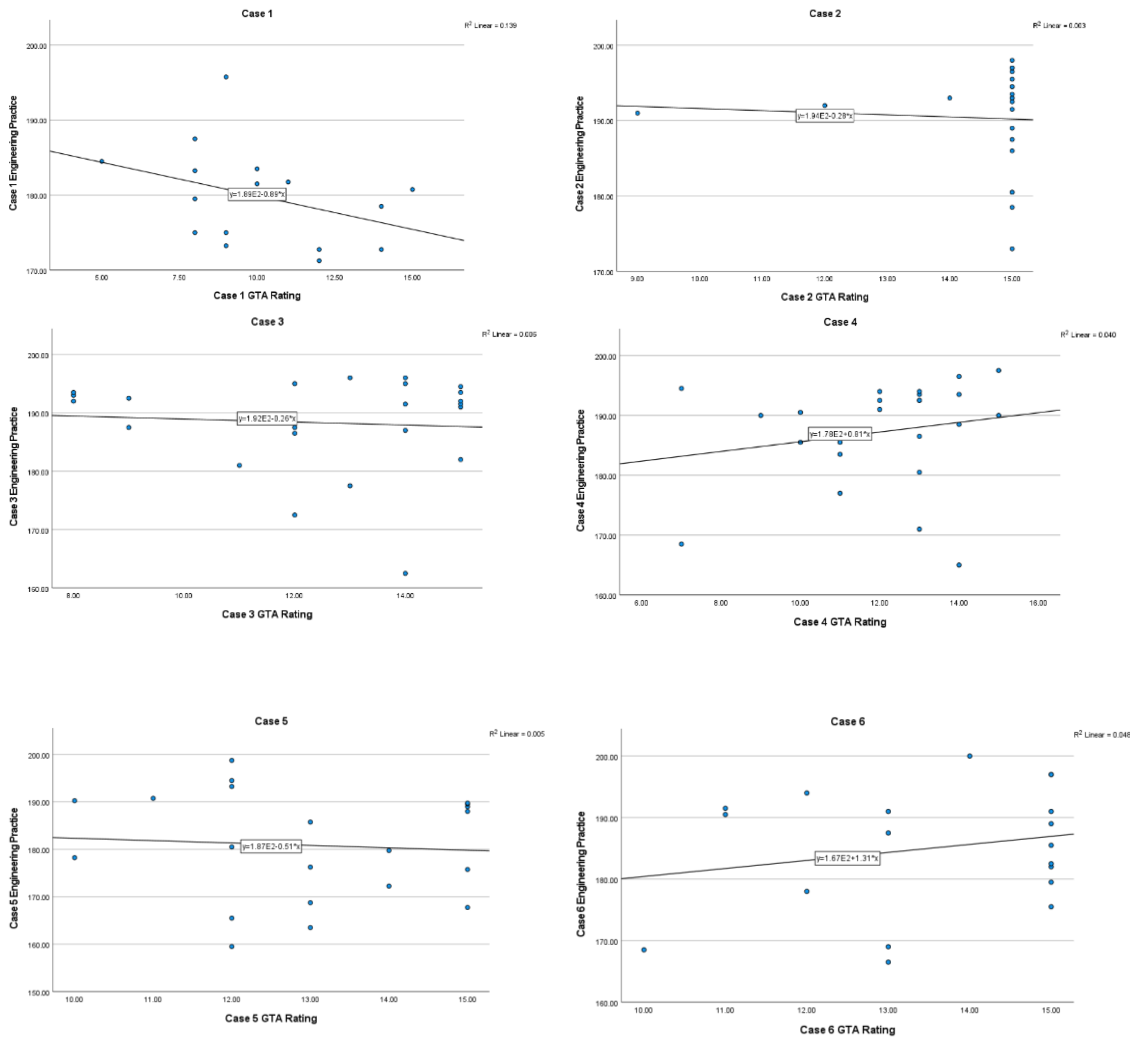
Phase 2: Team Performance Relationships

A Pearson's product-moment correlation was run to assess the relationship within each case, at the team-level, between the GTA ratings of *Team Effectiveness* (Appendix C) and *Engineering Practice;* the aggregated, capstone design project scores (Appendix D and E).

Preliminary scatter plot analysis for each case showed the relationship to be dependent upon the directional spread of GTA ratings of Team Effectiveness. For example, the plot of engineering practice to GTA ratings in case 2 showed most data points oriented along the highest GTA rating value (15) because all but two teams in case 2 were rated with the highest GTA rating for team effectiveness. The scatter plots used for preliminary analysis, for each case, are in Figure 4-13.

Figure 4-13

Team Effectiveness and Engineering Practice Scatter Plots for each case



Even though the degree of linearity varied from case to case, the robustness of the Pearson correlation test provides some confidence in its use for this cross-construct analysis. The resulting correlation of aggregate engineering practice scores (see Appendix D and E) with team effectiveness ratings (see Appendix C) are available, in Table 4-12.

Table 4-12

Correlations between Team Effectiveness and aggregate Engineering Practice

	Aggregate Engineering Practice	
Team Effectiveness (GTA Rating)	Case 1	*r(15)= - .37, p=0.14*
	Case 2	*r(20)= - .06, p=0.79*
	Case 3	*r(21)= - .077, p=0.73*
	Case 4	*r(22)=.20, p=0.35*
	Case 5	*r(19)= - .073, p=0.75*
	Case 6	*r(17)=.22, p=0.37*

A non-significant correlation between the aggregate engineering practice and team effectiveness construct was found for all cases. Any strong interpretations of directionality of relationship are not advisable due to the non-significance of the relationship.

Despite no statistically significant correlations, a few of the weaker trends present in this analysis might offer beginning points for later interpretation in phase 3, cross-case. Case 1 had the strongest relationship between aggregate engineering practice and team effectiveness, with a negative correlation (*r=-.37*); this result is somewhat puzzling as it indicates teams in case 1 with high ratings of team effectiveness received lower aggregate engineering practice scores.

The results from case 4 and 6 are the next stronger relationship after case 1 and are both in the anticipated directionality of relationship that an increase in team effectiveness rating may also lend to a higher engineering practice score. The remaining cases, 2, 3, and 5, have correlation coefficients near zero, leaving no relationship to mention.

Because the technical writing component of the overall engineering practice score showed the most variability (see Figure 4-5) and since the technical writing component was the portion completed by teams most independently without option for multiple feedback and input cycles from the GTAs, that particular component may have been more sensitive to team effectiveness functioning. Using only the technical writing engineering practice scores, a second correlation of technical writing and team effectiveness was conducted, for each case. The results are shown in Table 4-13.

Table 4-13

Correlations between Team Effectiveness and Technical Writing

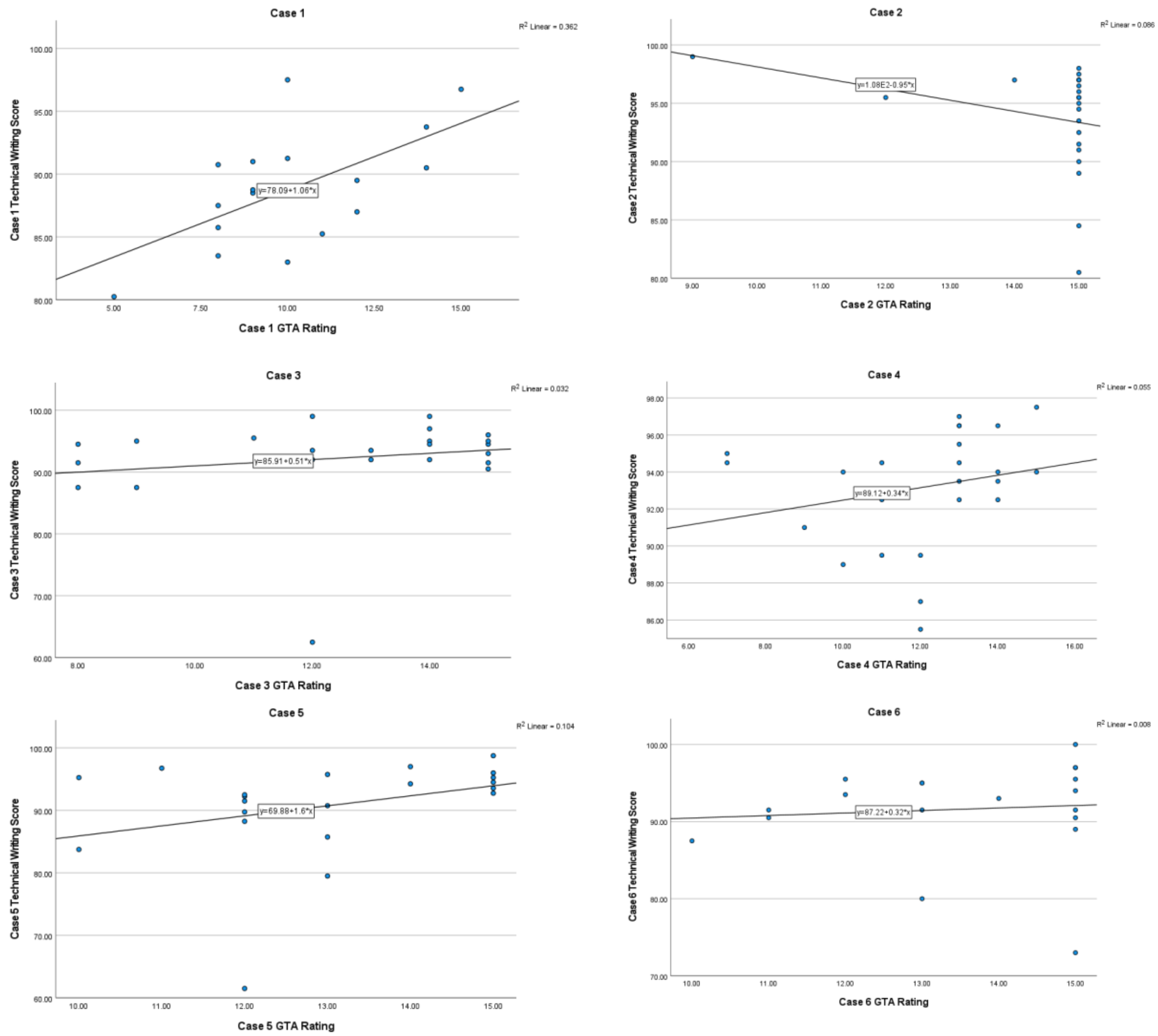
	Technical Writing (Engineering Practice)	
Team Effectiveness (GTA Rating)	Case 1*	*r(15)=.602,* ***p=0.011***
	Case 2	*r(20)= -.294, p=0.185*
	Case 3	*r(21)=.179, p=0.414*
	Case 4	*r(22)=.234, p=0.272*
	Case 5	*r(19)=.322 , p=0.155*
	Case 6	*r(17)=.218, p=0.369*

Note. * indicates significant at the 0.05 level.

Case 1 was statistically significant when the technical writing score was correlated with team effectiveness, *r(15)=.602, p=.011*, demonstrating a relatively strong relationship in the positive direction. In comparison with the results in Table 4-12, the technical writing score may be more sensitive to the strength of the team effectiveness metric. The scatterplots for this relationship, for each case, are in Figure 4-14.

Figure 4-14

Team Effectiveness and Technical Writing Scatter Plots for each case



Case 2, for this correlation, was the only negative relationship (*r=-.294*); however, inspecting the scatterplot in Figure 4-14, there is an outlier that corresponds with a GTA rating of 12 that seems to be causing the directional divergence. The remaining cases (3, 4, 5, and 6) were all positive correlations with no statistical significance. They all demonstrated the expected tendency towards a positive relationship that a higher team effectiveness, the higher the technical writing score; a relationship discussed further in chapter 5.

Phase 2: Teamwork Perceptions Relationships

The three measures for teamwork perceptions were collected at the individual-level; however, because of the anonymous nature of the data for two of the measures (Student Teamwork Perceptions Survey parts 1 and 2 – see Appendix A), only one of the measures (Peer Evaluations of Team Member Effectiveness – see Appendix B) was collected in such a way that it could be translated into a team-level measure. While the peer evaluations that comprised the PETME measure (Appendix B) of teamwork perceptions were collected at the individual-level, the teams were identified allowing for the calculation of a team-level discrepancy range for each team. With only one team-identifiable measure of teamwork perceptions, it isn't possible to explore interrelationships of metrics within teamwork perceptions. However, the team-level identification of the PETME data does permit the relationship analysis of this particular teamwork perception metric with team performance constructs (team effectiveness and engineering practice) in the next section.

Phase 2: Team Performance and Teamwork Perceptions Relationships

A Pearson's product-moment correlation was run to assess the relationship between *Team Effectiveness* (see Appendix C) and *Team Discrepancy* at the third timepoint of data collection for the PETME (see Appendix B). The third timepoint of data collection is near the same time in the semester that the GTA ratings for team effectiveness were collected, and thus represents the most reasonable timepoint at which to explore interrelationships given the alignment of the temporal data collection. Using the third timepoint for this within each case, at the team-level correlation provides insight and alignment with end of semester relationships among constructs. The peer evaluation (PETME) metric for this analysis is team discrepancy scores found for each team within each case in Phase 1 (see Figure 4-12). The resulting correlations between team effectiveness and team discrepancy scores (PETME at timepoint 3) are in Table 4-14.

Table 4-14

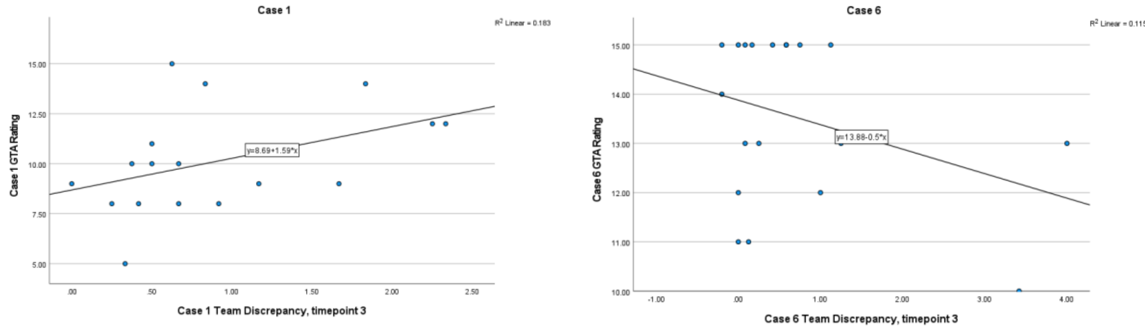
Correlations between Team Effectiveness and Team Discrepancy

	Team Discrepancy (timepoint 3)	
Team Effectiveness	Case 1	*r(15)= .43, p=0.087*
	Case 2	*r(20)= .11, p=0.622*
	Case 3	*r(21)= .12, p=0.594*
	Case 4	*r(22)=.-.04, p=0.847*
	Case 5	*r(19)=.-.02 , p=0.917*
	Case 6	*r(17)=.-.34, p=0.155*

Cases 2, 3, 4, and 5 had such low correlations that there is essentially no relationship. Case 1 was approaching significance with a moderate correlation at timepoint 3 ($r=.43$, $p=.087$). Case 6 also demonstrated a somewhat larger correlation than the other cases but in the opposite direction, $r=-.34$, $p=.155$. The scatterplots for Case 1 and 6, for association are provided in Figure 4-15.

Figure 4-15

Cases 1 and 6, Scatterplots of Team Effectiveness and Team Discrepancy (timepoint 3)



The scatterplots in Figure 4-15 display the opposite correlational directions between cases 1 and 6. Visual inspection of the scatterplots presents a better understanding of the correlational strength differences between case 1 (*r=.43*) and case 6 (*r=-.34*). The positive association for case 1 is representative of the variation of team discrepancy scores as compared to the negative association for case 6. There were more teams with higher discrepancy scores in case 1; whereas, for case 6 most teams had lower discrepancy scores. 2 teams from case 6 had exceptionally high discrepancy scores, causing the correlation between the team effectiveness ratings and case 6 discrepancy scores to have a negative association.

The correlation between technical writing, *Engineering Practice* scores (see Appendix E) and *Team Discrepancy* at timepoint 3 (*PETME*, see Appendix B) was conducted to investigate if there is a relationship between engineering practice (technical writing) and team discrepancy scores (PETME) at timepoint 3. Recalling rationale from before, the distribution of technical writing scores, per case, demonstrated better distribution than that of the aggregate engineering practice score. Continuing from that justification, technical writing scores will represent engineering practice for the performance of teams in each case. The resulting correlations between engineering practice and team discrepancy are in table 4-15.

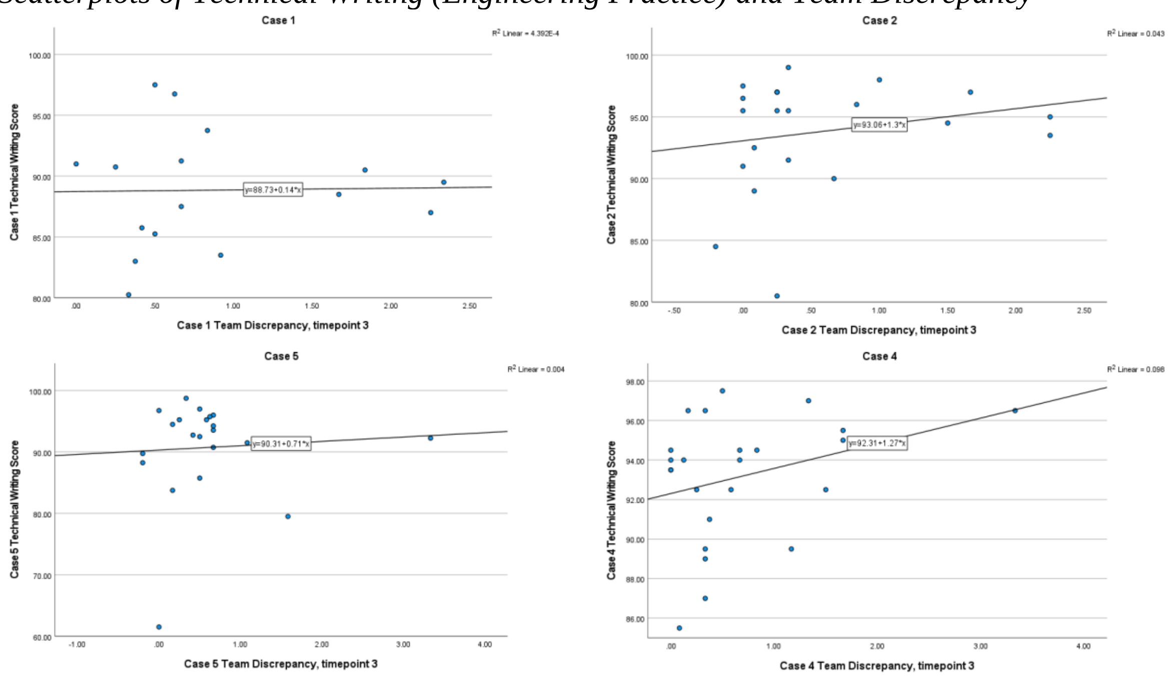
Table 4-15

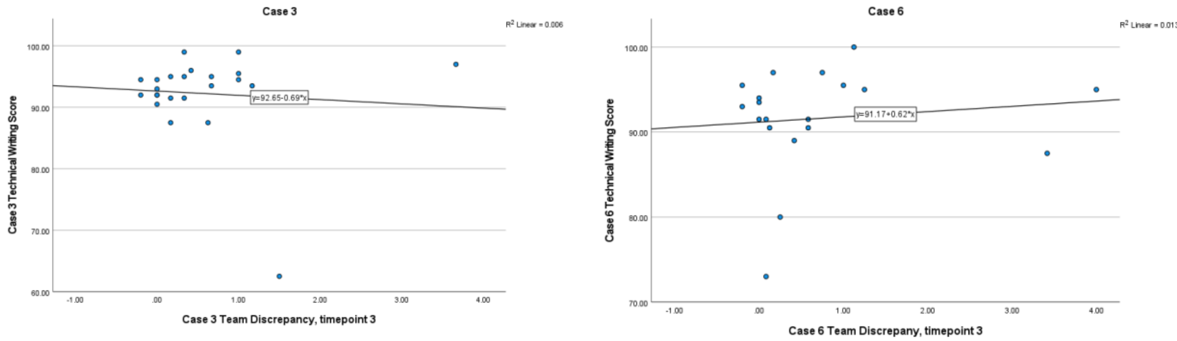
Correlations between Technical Writing and Team Discrepancy

		Team Discrepancy, timepoint 3
Technical Writing (Engineering Practice)	Case 1	*r(15)=-.080, p=.716*
	Case 2	*r(20)=.207, p=.356*
	Case 3	*r(21)=.021, p=.936*
	Case 4	*r(22)=.313, p=.137*
	Case 5	*r(19)=.065, p=.780*
	Case 6	*r(17)= .114, p=.643*

Figure 4-16

Scatterplots of Technical Writing (Engineering Practice) and Team Discrepancy





Phase 2: Team Performance and Teamwork Perceptions Across the Semester

A Pearson's product-moment correlation was run to assess the relationship between *Team Performance* and *Teamwork Perceptions* at all timepoints of data collection. This perspective provides a look at the constructs across the semester and provides insight into if there were possible 'early warnings' of team dysfunction or team cohesion. The constructs used to explore these interactions included: GTA ratings of *team effectiveness* (see Appendix C), the technical writing scores of *engineering practice* (see Appendix E) and team discrepancy values at across all timepoints of the *PETME* measure (see Appendix B).

Team Effectiveness and Team Discrepancy. A correlation was run to assess the relationship between *team effectiveness* (see Appendix C) and *team discrepancy* across all timepoints of peer evaluations using the PETME measure (see Appendix B). The results are in table 4-16.

Table 4-16

Correlations of Team Effectiveness and Team Discrepancy

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Mean(n)	*10.12(17)*	*14.55(22)*	*12.48(23)*	*12.04(24)*	*13(21)*	*13.53(19)*
Construct			Team Effectiveness			
PETME Timepoint 1	***r=.51 p=.04****	*r= -.071 p=.75*	*r=.086 p=.70*	*r=.084 p=.70*	*r=.22 p=.35*	*r=-.19 p=.44*
PETME Timepoint 2	***r=.395 p=.12***	*r=.08 p=.73*	*r=.11 p=.61*	*r=-.03 p=.91*	*r=.05 p=.82*	*r=-.36 p=.13*
PETME Timepoint 3	***r=.43 p=.09***	*r=.11 p=.62*	*r=.12 p=.59*	*r= -.04 p=.84*	*r= -.02 p=.92*	*r=-.34 p=.16*

Note. * indicated statistical significance at the $p<.05$ level.

There was a statistically significant, strong positive correlation for case 1 between team discrepancy and team effectiveness at timepoint 1, $r(15)=.51$, $p=.04$. The direction of this correlation goes against the expectation; the interpretation would mean the higher the discrepancy of a team the higher the team effectiveness rating. This result is perplexing, and more discussion will be taken up in Phase 3 and Chapter 5.

Case 1 and 6, at timepoint 2 had non-significant, moderately positive ($r>.3$) associations, in opposite directions. The remaining associations between team effectiveness and the collection timepoints for peer evaluations were very small, indicating there to be no relationship.

Engineering Practice and Peer Evaluation. A correlation was run to assess the relationship between *Engineering Practice* using the technical writing scores (see Appendix E) and *team discrepancy* across all timepoints of peer evaluations using the PETME measure (see Appendix B). The results are in Table 4-17.

Table 4-17

Correlations of Technical Writing and Team Discrepancy

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Mean(n)	*88.85(17)*	*93.79(22)*	*92.26(23)*	*93.17(24)*	*90.73(21)*	*91.61(19)*
Construct	**Technical Writing (Engineering Practice)**					
PETME Timepoint 1	*r=.06* *p=.82*	*r=.26* *p=.25*	***r=-.42*** ***p=.04****	*r=.25* *p=.24*	*r=.25* *p=.27*	*r=.07* *p=.77*
PETME Timepoint 2	*r=-.01* *p=.98*	*r=.18* *p=.42*	*r=-.22* *p=.31*	*r=.30* *p=.15*	*r=.11* *p=.63*	*r=.13* *p=.61*
PETME Timepoint 3	*r=.021* *p=.936*	*r=.21* *p=.36*	*r=-.08* *p=.72*	*r=.31* *p=.14*	*r=.07* *p=.78*	*r=.11* *p=.64*

Note. * indicated statistical significance at the p<.05 level.

There was a statistically significant, moderately negative correlation, *r=-.42, p=.04*, between timepoint 1 of the peer evaluations for case 3. A result that aligns with the expectation that a higher team discrepancy (PETME), the lower the engineering practice score. The remaining associations between aggregate engineering practice and the collection timepoints for peer evaluations were very small, indicating there to be no relationship.

Phase 3: Cross-Case

This third phase brought together case comparisons seeking patterns exhibited by the six specific cases of this study. Guided by the research questions, this phase presents the patterns that were common among multiple cases or unique to some. Patterns highlighted will be discussed in greater detail in Chapter 5.

Phase 3: Case 1 Different from the Rest

Case 1 presented the most unique characteristics of all the cases. Consistently different, in varying capacities, case 1 separated itself from the rest of the cases across both engineering performance and teamwork perceptions. Case 1 consisted of 17 teams and 66 students, plus a GTA and two engineering faculty who were accessible to students when questions arose.

The breakdown in continuity began with the demonstrations of engineering performance. More than any of the other cases, most of the teams in case 1 were overwhelmingly “low” in their team effectiveness (see Figure 4-2). The categories of team effectiveness were constructed from the ratings provided by the GTA for each case; GTAs held intimate knowledge of the functioning capabilities of each team. GTAs were systematically integrated into the interactions of teams, positioned as the first source of course information and they managed student grades and documents for the course in which they were responsible. A case with a consistently “low” effectiveness means teams of case 1 encountered dysfunction that drew the attention of the GTA that carried throughout the evaluation of the entire semester.

The performance on the cornerstone design project (see Figure 4-7) illuminated another aspect of uniqueness with case 1. Within the scoring features of engineering practice (technical writing), more teams in case 1 qualified to be “intermediate” in terms of the technical writing feature of engineering practice. While “intermediate” isn’t the lowest category within this construct, when compared to other cases (e.g., case 2), most had teams qualify to be in the “proficient” or “exceptional” (top two) categories. The most difference was noticed between cases 1 and 2; among the teams of each case 76% of teams in case 1 were “intermediate” while 77% of teams in case 2 were “proficient” or higher. Overall, case 1 proved to be lacking across the measures of engineering performance.

A team's capability to produce an elegant final-design product has been shown previously to have connection to the learning environment. Spaces such as makerspaces contain characteristics that generate creative processes and opportunities for collaborative thinking and teamwork, characteristics that appear to have vital importance to producing an elegant final-design product; an outcome that also demonstrates effective team performance (Goldman et al., 2014). Case 1 demonstrated a lower-than-average performance, as evidenced by the results of engineering practice and team effectiveness (see Table 4-3). Learning environment, as supported by these results, influences the outcomes of a team's performance, and holds relevance to the interactions of others within the environment. These interactions, either between students, teams (both within teams and across teams), faculty, GTAs are important in the outcome of a team's performance.

Exploring t*eamwork perceptions* of case 1, the team discrepancy scores from the peer evaluations (see Figure 4-12) show some students within case 1 had the perception that there was dysfunction within their team. The team discrepancies (PETME, see Appendix B), for each team at each timepoint were noticeably different for case 1 than the other cases at each timepoint. For each team discrepancy at each timepoint, case 1 had more teams with higher discrepancies than any of the other cases. This is not to say that case 1 was entirely dysfunctional. Figure 4-12 shows many teams remained non-discrepant throughout the semester; evidenced by the green areas of the 3-dimensional surface graph for case 1. In comparison with other cases, case 1 had more teams containing team members that evaluated one another in ways that varied enough to show higher discrepancies.

A correlation analysis of team effectiveness and team discrepancy (see Table 4-16) revealed case 1 team effectiveness (GTA ratings) to be lower, in comparison to other cases, than team discrepancies (PETME) for all time points. Case 1 p-values are all substantially lower (trending toward significance) even at the earliest timepoint in the semester. This reasonably strong, positive directional outcome is opposite of expected; interpreted as the higher the team discrepancy the higher the effectiveness. This result is likely due to the statistical distribution of this case having a proportionally larger number of low effective teams and a relatively lower number of highly discrepant teams. Therefore, this relationship should not be used as a predictive indicator for future team effectiveness. Additional discussion of this correlation will be taken up in Chapter 5.

Phase 3: Technical Writing Sensitive to Team Functioning

The technical writing score appeared to have more of an ability to extract team functionality than the totaling of all the scores featured for the cornerstone design project. The correlation results in Phase 2 between *team effectiveness* and technical writing (see Table 4-13 and Figure 4-14) proved to be more discriminatory than that of the correlation analysis using the total of the 3-feature scores (see Table 4-12 and Figure 4-13). This variability of the technical writing feature (see Figure 4-5) and the team effectiveness characteristics required by teams to complete as an assignment for the course, made technical writing more sensitive to team effectiveness and a more operational variable.

This sensitivity to team effectiveness was also evidenced through the statistically significant correlation of team effectiveness and performance with technical writing scores as the performance indicator (see Table 4-13). The correlation of team effectiveness and engineering practice (technical writing) found a statistically significant result in case 1**,** *r(15)=.602, p=0.011*. Additional correlations, while not significant, were notable and provide more insight into the sensitivity technical writing has in extracting team effectiveness; positive moderate correlations were found in *c*ase 5 (*r=.322*) and case 4 (*r=.234*). The positive directions of these correlations are fit expectation that higher team effectiveness will lead to higher engineering practice.

A sensitivity to team functioning was also revealed in the correlational analysis of team discrepancy (PETME) and technical writing score (engineering practice) in Table 4-17. Case 3 at timepoint 1 was statistically significant with a strong negative correlation (*r=-.42, p=.04*), or the more discrepant a team is the lower their performance will be on their final product (technical writing). While not significant, case 4 had moderate correlations at each timepoint of the peer evaluations, trending toward significance and elevating the technical writing score as a variable sensitive to the characteristics of team functionality.

Phase 3: Collective Efficacy Calibration with Experience

Collective efficacy is a construct that is constantly adjusted based on the engagement and experiences of team members. When a teammate is inconsistent with their communication with the team, or lacks a clear understanding of the team's goals, or simply doesn't show up to work with the team the remaining members will recalibrate their belief in the team's ability, based on those experiences. This is depicted in the collective efficacy decline of case 1. Case 1's gradual downward trend to the lowest case collective efficacy by the end of the semester (Figure 4-10) indicates that through the experiences with team members, student's beliefs about their team's ability declined over time. Drawing on the evidence of "case 1 difference from the rest" section, the students in case 1 perceived the dysfunctionality with their team leading to an overall decline in collective efficacy that what much larger than other cases. This reduction of collective efficacy is consistent with previous evidence that case 1 included the largest proportion of low functioning teams (see Figure 4-2) and the fewest teams of ‘proficient or better’ in performance (see Figure 4-7).

Case 2 in Figure 4-10 was the only statistically significant increase in collective efficacy by the end of the semester. Throughout the semester, case 2 demonstrates a fluctuation in collective efficacy, especially at mid-semester (timepoint 2) when teams are engaged in the task at hand and the necessity of team effectiveness is evident. Case 2 was comprised of teams at or above proficient in performance (Figure 4-2), suggesting the mid-semester drop in collective efficacy reflects the challenge even strong teams experience when in the process of ‘gelling’ toward team cohesion. Oakley et al. (2004) add that engineering educators supportive of student’s development of effective team processes can bolster student’s positive perceptions of work in teams. Case 2 confirms this idea, by the end of the semester most teams appear to have figured out this process, based on their performance (Figure 4-7) and their recovered mean collective efficacy at the end of the semester. The difference from mid- to end-of-semester was statistically significant, indicating that teams recognized the improvement in team effectiveness which improved their perceptions of working on a team.

Phase 3: Consistent Recognition of Effective Team Characteristics

A consistent pattern emerged based on the judgements students shared through their rankings of effective team characteristics (see Appendix C). Figure 4-11 reflects the collective forced rankings of students across all cases and all timepoints of data collection. Despite the substantial difference of team effectiveness performance (Figure 4-2) noted earlier between cases 1 and 2, and middle cases 3, 4, 5, and 6; all cases, at all timepoints consistently ranked the 6-team effectiveness characteristics in similar order of importance. Thus, supporting the idea that no matter how well team did or did not function, it seems most students hold similar judgments of the relative importance of specific characteristics to be effective as a team.

In connection to this consistent recognition by students, GTA comments on team's effectiveness also demonstrated a strong prevalence of communication as an essential element attributed to a team's ability to perform. Table 4-3 presents the effectiveness themes among the categories of teams. Noticeable from those results is the progression of communication characteristics among teams from the lack of mature communication in "low" and "moderate" teams to fluid communication in "high" teams. The lack of communication appeared to directly connect in GTA comments of "low" and "moderate" teams' inability to manage the purpose and clarify goals of the team. While the "high" teams demonstrated exceptional role clarity and clear common purpose. It seems that both students of the course and GTAs were acutely aware of communication as a most essential characteristic of effective teams; when communication was lacking, a team's effectiveness also declined.

CHAPTER V: DISCUSSION

The specific purpose of this study was to explore if a makerspace learning environment is effective in promoting student team performance in team effectiveness and engineering practice. This chapter discusses the findings in order of the research questions that addressed the purpose of this study. A summary of conclusions, implications, and future research will close the chapter.

RQ1: Engineering Performance in a Makerspace Team Environment

The makerspace learning environment explored in this study promoted characteristics that generated collaboration of intellectual exploration and teamwork, fundamental to producing elegant design products that demonstrate effective team performance (Goldman & Zielezinski, 2016). The cohort of teams in this study demonstrated exceptional levels of engineering performance, apart from one unique case, teams achieved exceptional outcomes.

1a. Team Effectiveness. The performance and effectiveness of student teams is strongly influenced by individual student's initial perception toward the use of team as a mechanism for a successful collective learning experience (Lent et al., 2006). Most teams in this study were effective as a team. Able to efficiently manage the process of the ill-structured design project by communicating, collaborating, and ultimately executing tasks toward achieving the team's goal. Kozlowski (2007) describes this as a team cognition; for a team to be effective in achieving their goal the members must (1) hold themselves accountable and (2) maintain awareness of their teammates' knowledge of the team's objectives. The teams of low effectiveness tended to diverge within one or both areas.

The progression from novice to expert is refined through experience and engagement within the environment and with the available resources and tools. A team's effectiveness in utilizing the resources and tools (e.g., GTAs, faculty, physical tools) often impacted their productive use of time with their team, during class. Evidenced by GTA comments, teams low in effectiveness, often "*did not handle [the] long project well"* or experienced a *"power struggle… [unable to] work well together"*.

A common impression of teamwork as a part of a course, particularly among first year engineering students, is that the complex problem can be divided up into a series of smaller tasks. These tasks can then be divvied between the members of the team as disparate elements and then will come back together at the end. However, the design of the course at the heart of this study dispelled that impression, minimizing the 'lone wolf' tendency of engineering students (Barr et al., 2005), and exposes those teams attempting this route of teamwork at each step. The cornerstone design project was created with ill-structured elements that necessitated teams continually communicate, collaborate, and creatively approach solutions.

1b. Engineering Practice. As a cohort, teams generated exceptional to proficient engineering practice scores across all measures. The design of each measure for engineering practice was the result of careful consideration by the entire faculty and GTA group. To achieve exceptional scores teams were required, by means of experience, to use team effectiveness skills throughout the semester to effectively achieve completion of the goal/product. The technical writing feature alone required students engage with one another outside of the specified hours of class each week. This necessitated at minimum, the use of 3 effective team characteristics: mature communication, accountable interdependence, and a clear common purpose (Adams et al., 2002) The task in getting the writing completed, as a team, was the responsibility of the team. The responsibility of ensuring teams were equipped with resources to complete the technical writing was taken up by the faculty and GTAs of the course.

The design course faculty and GTAs were specific in their instruction of expectations for the technical writing. They did not simply deliver the teams a rubric and assignment description; rather, the task of technical writing was an expectation from the beginning of the semester. Elements of the technical writing were first shared through the course syllabus, as a learning outcome of the course. Faculty also provided instructional support on crafting technical writing, using the classroom space within the makerspace to demonstrate to students how to construct the technical document and where to gather the information necessary for a thoughtful writeup. The syllabus also outlined two feedback loops in which students were expected to submit portions of their technical writing to their GTA and feedback was provided thereafter. Engineering courses focused on design, especially those created for first-year engineering students, have seen success in student motivation by approaching problem-solving in a scaffolded manner and gradually releasing to ill-structure problems with greater complexity (Ge & Land, 2003). While this study did not measure student motivation, more than half of all teams in the entire cohort were proficient or exceptional in their engineering practice; evidence that students were motivated as a team to reach a high level of success in completing the ‘wicked’ cornerstone design project.

Many engineering students hold an unrealistic view that engineering practice is synonymous with only technical problem solving, even when they’ve completed design projects (Sheppard et al., 2010). To address this misconception and to provide students engineering practice development opportunities, engineering education programs are integrating more cognitive apprenticeships (Collins et al., 1991; Dennen & Burner, 2008) that exposes students to professional practice through carefully staged and monitored steps. The experience of teamwork, while engaging in the engineering practice of the cornerstone design project, within the makerspace learning environment of the engineering design course is indicative of a large-scale apprenticeship. The faculty and GTAs carefully staged and monitored the steps of the practice and thus, most teams in the cohort experienced success in learning that well surpassed technical problem solving only.

RQ2: Teamwork Perceptions in a Makerspace Environment

The initial perception of teamwork among many first-year engineering students can be negative due to previous undesirable team experiences or a past dysfunctional team performance (Ruiz Ulloa & Adams, 2004). When engineering educators support student teams in their development of team effectiveness and functioning a student’s perceptions of teamwork increases (Oakley et al., 2004). The dysfunction of teams within the cohort of this study, represented by team discrepancy, escalated at the end of the semester among teams that tended to be lower in team effectiveness ratings. At the end of every semester, engineering students have an increase of stress and pressure due to the on slot of final exams, larger assignments, or a presentation of a complex design solution to an ill-structured design problem. This study noted an influx of teams with higher team discrepancy at the end of the semester, confirming that when pressure on a team to perform is coupled with inconsistencies of team effectiveness, teams are unlikely to perceive the teamwork experience positively. However, teams that persist in their quest of improving team effectiveness are often less phased by the effects of added pressure, exuding collective efficacy in their team and its ability to succeed.

The engineering design course beneficially incorporated peer evaluation as a required submission of all students. Peer evaluations create accountability to teammates and provides incentive for displaying good interpersonal skills and contributing effort to help the team achieve its goals (Cestone et al., 2008; Levine, 2012). Individual accountability is necessary in TBL methods and when absent can lead to student's negative perceptions of teamwork (Finelli, Bergom, & Mesa, 2011; Oakley et al., 2007). The number of highly discrepant teams, for the entire cohort across the semester, was relatively small. The combination of peer evaluations, course support (e.g., instructors, resources) of teams in their development of team effectiveness, and the necessity of collaboration incorporated by the team-based learning structure of the course had positive outcomes for teamwork perception across cases.

An exception to this postulate is the differences presented by case 1. While this study did not examine the individual characteristics of students within each case, case 1 did have unique struggles among a larger proportion of individual students as evidenced by the larger proportion of discrepant teams (when compared to the other cases). The much larger proportion of low effectiveness teams in case 1 is also suspect as impacted by individual student metrics that, for this study, was not measured. Notable in this discussion is the lack of female representation in case 1. While the comparisons of cases showed case 1 to be different from the rest, when examined within case, most teams were consistently low in discrepancy and most performed adequately. Potentially, an instructor could use the team discrepancy scores as a metric to identify teams in need of additional team cohesion attention. Yet, it is not suggested that an instructor assume teams of initial high discrepancy will have lower performance than team of less discrepancy.

Collaboration among students can lead to intrinsic motivation, increased persistence, and greater transferability of skills (Pfaff & Huddleston, 2003). Innovation is often sparked by teamwork involving the intersection of multiple disciplines (Denison, Hart, & Kahn, 1996; Rhee, Parent, & Basu, 2013). Team experiences throughout the semester emerge through expressions of collective efficacy. Case 2 contained most of the strong performing teams in the cohort and reported the strongest growth in collective efficacy. These findings complement the studies that support the collaborative nature of learning; teams reach high performance through the multiplicities of consistent engagement and continued motivation and persistence. The tensions that escalated at the end of the semester, were in part due to the complexities of the ill-structured, ‘wicked’ problem (Lönngren, 2017). Tensions, in this study, appeared to extract areas of team effectiveness for most of the teams resulting in exceptional engineering performance; where teams were less than exceptional could reveal areas team effectiveness to focus on through instruction and training through the course semester.

Learning in Makerspaces

The learning environment informs the experience of the learner. Several studies have depicted makerspaces as promising sites for student engagement and learning (Barton et al., 2016; Bevan, 2017; Giannakos et al., 2015); adding, that makerspaces appeal to student's need to engage passionately with learning objectives that require them to participate inquisitively, being more than a passive consumer (Halverson & Sheridan, 2014). The inherent features of teamwork and engineering design thinking present in a makerspace have garnered excitement among engineering educators and leaders (Lenhart et al., 2020). Makerspaces, however, can only have impact on the learning experience of the student when the pedagogical decisions made prior to the start of the course incorporate resources and supports that instill teamwork as a necessary and ever evolving skillset.

The course at the center of this study is the culmination of careful thought and thorough pedagogical decisions that integrate a team-based learning experience to engage and motivate engineering students to strive for excellence in team performance throughout the semester. Results of this study revealed most teams across the cases experienced multiple positive performance outcomes. The course structure was designed to bolster team's performance outcomes by incorporating engineering design thinking as a mental model for approaching teamwork and encouraging teams to continue to iterate their design.

The engineering faculty and GTAs provided students fluid feedback during the process of class time, bolstering the engineering design idea of iteration, resulting in teams achieving performance success despite the team's starting point. The open physical environment of the makerspace afforded students, faculty, and GTAs the ability to move around as needed; an element of the learning environment that facilitates communication, community building, and critical exploration of thinking and idea generation. This kind of community skill building and connecting diverse disciplines and individuals gives rise to continual learning that is important in the development of emerging engineers (Choi et al., 2021) This study has shown that a well conceptualized formal makerspace course for first-year engineering students can build in team-based experiences that support the development of emerging engineers. Acquiring effective team skills and positive perceptions of teamwork in the first year of their engineering program is instrumentally helpful to their future engineering team contributions.

Team-Based Learning

Team-based learning (TBL) is an essential component of engineering education and core to the pedagogy of this study's course context. The ability to function and perform in teams is an important pedagogical outcome that deserves unique attention. Of the four essential elements of TBL (Michaelsen & Sweet, 2008) the course at the center of this study reflects them all by: 1) teams are intentionally formed with members of varying discipline-specified engineering majors, 2) faculty and students utilize online software that maintains accountability for specific individual and team assignments, and 3) feedback is an expected and executed instructional strategy utilized by faculty in all forms of assessment.

This study adds to the growing body of literature in TBL, expanding the understanding of student experiences as they engage in TBL as a learning participant. The enhancement of engineering performance outcomes and teamwork perceptions of students following the TBL experience, as demonstrated by this study, is of relevance to the field of engineering education. An essential element of TBL is the implementation of ill-structured problems (Jonassen, 1997). The ill-structured problem in this study, presented students and their teams a complex design problem, centered around the cornerstone design project. The project was multifaceted and required various demonstrations of team effectiveness by team members to be successful as a team, in presenting an efficiently functional windmill.

The structure of the ‘wicked’ problem, situated such that multiple aspects of the problem were not well specified, posed unique challenges to teams. These unique challenges created tensions and dysfunction, evidenced by the collective efficacy perceptions across the semester. Case 2 demonstrated a successful emergence of collective effectiveness in overcoming tensions presented mid-semester as teams began experiencing the pressures and struggles brought on by the increased workload and scheduled deadlines of the team project. The teams of case 2, overall, emerged from the pressure and struggle to perform successfully and effectively. Showing that in team-based learning experiences the structure of the problem should be wicked, forcing teams to find their methods toward effectiveness and cohesion.

The performance of teams was overwhelmingly successful. All teams completed the project, to some degree; most teams performing at a proficient to exceptional level across all the engineering performance measures. Ill-structured problems are cited as similar to that of an engineering workplace, both complex and ill-defined (Jonassen et al., 2006). Engineering courses, specifically those created for first year engineering students, that integrate problems in a scaffolded manner, gradually releasing to the ill-structured problem are more likely to see success in student motivation toward approaching problem-solving in a team setting (Ge & Land, 2003). Competencies relevant to the professional practice of engineering are intertwined with teamwork effectiveness, identifiable through the successful performance of collaboration, communication, creative problem solving (Passow & Passow, 2017).

Conclusions

Team performance is indicative of the course-level supports and the team-level engagement present in a learning environment. The makerspace learning environment of this study proved to be effective in promoting collaboration, communication, and effective approaches to the wicked design problem. Most teams were effectively able to utilize team effectiveness skills when needed. Teams that lacked the ability to access effectiveness skills were supported by the instructors in the development of those skills, resulting in a positive overall perception of teamwork. Team communications emerged as the most important characteristic of effective teams and growth in collective efficacy proved to have a positive association with a team's performance.

The successful promotion of performance and positive gains in teamwork perceptions through a team-based learning course in a makerspace is due to the careful and deliberate choices that went into each pedagogical element of the engineering design course. Essential elements of the course design that aided in the positive outcomes included the use of scaffolded supports that gradually release teams into the ill-structured, wicked problem. The makerspace encouraged collaboration and communication of teams as a by-product of the space available; however, the performance and perception gains were due to the community of teams and instructors consistently communicating and collaborating.

Implications of the Study

This study has several implications for research and practice. In terms of research, the makerspace presents a unique learning environment with innate features that encourage and bolster the value of teamwork among students. The importance of effective teamwork skills, specifically for engineers, was communicated using team-based learning strategies that enhanced the necessity for collaboration and communication. Taken together, these results suggest that future research with similar contextual elements could build from the constructs of this study. An implication of this is the enhancement and continued refinement of the measures for which the constructs were informed.

Implications of practice congeal around the learning environments that share characteristics of makerspaces that can incorporate some of the characteristics of the design course. The main aim of this this study was to explore makerspace learning environments as a potential promising site for promoting engineering performance and teamwork perceptions among first year engineering students. This study contributes to new understandings for engineering education. The structure of the academic makerspace learning, and the pedagogical decisions involved in implementing a TBL experience are crucial to achieving positive team performance and teamwork perception outcomes. This study also contributes to new understandings of a TBL experience on first-year engineering student's teamwork perceptions and performance of engineering practices and effective teamwork.

Recommendations for Future Research

This study employed a suite of instruments and scoring rubrics to measure the performance and perceptions of engineering students learning in a makerspace. Studies that investigate the inner working of teams and the ways their dynamics play out, while engaged in a wicked problem in a makerspace have the potential to expand upon these instruments of this study. Additional qualitative measures, such as focus groups, would assist in the follow-up question: *why do makerspace learning environments promote performance and perceptions of students?* Questions remain as to whether the same course design could be implemented in a non-makerspace environment and still get similar positive outcomes.

Makerspaces are oftentimes designed to bring together diverse users, activities, and communities. They are oftentimes explicitly described as places that enable and encourage interdisciplinary and cross-disciplinary work. However, questions remain as to whether these intended outcomes of an academic makerspace bear out in practice and whether users of makerspaces perceive the potential learning opportunities offered in university makerspaces in positive, welcoming spaces. These spaces are notably complex and messy; often leading to the diverse activities. It would be interesting and of interest to the community of makers to investigate how diverse groups interpret and enact learning through team-based, makerspace experiences. The makerspace community of researchers cite the need for more understanding of makerspaces, topics such as: how members of different communities come together to form new understandings (Choi et al., 2021).

REFERENCES

ABET. (2021). Criteria for Accrediting Engineering Programs, 2021-2022. Retrieved from https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2021-2022/#GC3

Adams, R., Turns, J., & Atman, C. (2003). Educating effective engineering designers: The role of reflective practice. *Design Studies*, *24*(3), 275–294.

Adams, S. G., & Laksumanage, B. (2003). Building successful student teams in the engineering classroom. *Journal of STEM Education*, *4*(3), 1–6.

Adams, S. G., Vena, L. C. S., Ruiz-Ulloa, B. C., & Pereira, F. (2002). A conceptual model for the development and assessment of teamwork. *Age*, *7*, 1.

Agresti, A. (2013). *Categorical data analysis*. *John Willey and Sons, USA* (3rd ed.). Hoboken, NJ: Wiley.

Alves, A. C., Mesquita, D., Moreira, F., & Fernandes, S. (2012). Teamwork in Project-Based Learning: engineering students' perceptions of strengths and weaknesses. In *Proceedings of the Fourth International Symposium on Project Approaches in Engineering Education (PAEE'2012),* (pp. 23–32). Paee'2012.

Archambault, R. D. (1964). *John Dewey on education: Selected writings*. New York: Modern Library.

Armstrong, E., & Thompson, K. (2003). Strategies for increasing minorities in the sciences: A University of Maryland, College Park, model. *Journal of Women and Minorities in Science and Engineering*, *9*(2).

Astin, A. W. (1993). Diversity and multiculturalism on the campus: How are students affected? *Change: The Magazine of Higher Learning*, *25*(2), 44–49.

Bandura, A. (1998). Personal and collective efficacy in human adaptation and change. *Advances in Psychological Science*, *1*, 51–71.

Bandura, A. (2011). Social cognitive theory. *Handbook of Social Psychological Theories*, *2012*, 349–373.

Bandura, A., & Wessels, S. (1997). *Self-efficacy*. W.H. Freeman & Company.

Barbour, R. S. (2001). Checklists for improving rigour in qualitative research: a case of the tail wagging the dog? *Bmj*, *322*(7294), 1115–1117.

Barbour, R. S., & Barbour, M. (2003). Evaluating and synthesizing qualitative research: the need to develop a distinctive approach. *Journal of Evaluation in Clinical*

Practice, *9*(2), 179–186.

Barr, T. F., Dixon, A. L., & Gassenheimer, J. B. (2005). Exploring the “lone wolf” phenomenon in student teams. *Journal of Marketing Education*, *27*(1), 81–90.

Barton, A. C., Tan, E., & Greenberg, D. (2016). The makerspace movement: Sites of possibilities for equitable opportunities to engage underrepresented youth in STEM. *Teachers College Record*, *119*(6), 11–44.

Bevan, B. (2017). The promise and the promises of Making in science education. *Studies in Science Education*, *53*(1), 75–103.

Bevan, B., Gutwill, J. P., Petrich, M., & Wilkinson, K. (2015). Learning Through STEM-Rich Tinkering: Findings From a Jointly Negotiated Research Project Taken Up in Practice. *Science Education*, *99*(1). https://doi.org/10.1002/sce.21151

Borrego, M., Karlin, J., McNair, L. D., & Beddoes, K. (2013). Team effectiveness theory from industrial and organizational psychology applied to engineering student project teams: A research review. *Journal of Engineering Education*, *102*(4), 472–512.

Brannick, M. T., Roach, R. M., & Salas, E. (1993). Understanding team performance: A multimethod study. *Human Performance*, *6*(4), 287–308.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42.

Calabrese Barton, A., & Tan, E. (2018). A Longitudinal Study of Equity-Oriented STEM-Rich Making Among Youth From Historically Marginalized Communities. *American Educational Research Journal*. https://doi.org/10.3102/0002831218758668

Capozzoli, T. K. (1995). Resolving conflict within teams. *The Journal for Quality and Participation*, *18*(7), 28.

Cestone, C. M., Levine, R. E., & Lane, D. R. (2008). Peer assessment and evaluation in team-based learning. *New Directions for Teaching and Learning*, *2008*(116), 69–78.

Choi, Y. H., Bouwma-Gearhart, J., Lenhart, C. A., Villanueva, I., & Nadelson, L. S. (2021). Student Development at the Boundaries: Makerspaces as Affordances for Engineering Students’ Development. *Sustainability*, *13*(6), 3058.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences. Abingdon. United Kingdom: Routledge.

Collins, A., Brown, J. S., & Holum, A. (1991). Cognitive apprenticeship: Making thinking visible. *American Educator*, *15*(3), 6–11.

Corbin, J., & Strauss, A. (2015). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Sage publications.

Creswell, J. W., & Clark, V. L. P. (2017). *Designing and conducting mixed methods research*. Sage publications.

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika*, *16*(3), 297–334.

Cross, N. (2001). Designerly ways of knowing: Design discipline versus design science. *Design Issues*, *17*(3), 49–55.

de Figueiredo, A. D. (2013). On the historical nature of engineering practice. In *Engineering Practice in a Global Context* (pp. 7–12). Informa UK Limited.

DeChurch, L. A., & Mesmer-Magnus, J. R. (2010). The cognitive underpinnings of effective teamwork: A meta-analysis. *Journal of Applied Psychology*, *95*(1), 32.

Denison, D. R., Hart, S. L., & Kahn, J. A. (1996). From chimneys to cross-functional teams: Developing and validating a diagnostic model. *Academy of Management Journal*, *39*(4), 1005–1023.

Dennen, V. P., & Burner, K. J. (2008). The cognitive apprenticeship model in educational practice. *Handbook of Research on Educational Communications and Technology*, *3*, 425–439.

Dewey, J. (1938). An as experience. *Education*.

Dougherty, D. (2012). The maker movement. *Innovations: Technology, Governance, Globalization*, *7*(3), 11–14.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education*, *94*(1), 103–120.

Evans, D. L., Beakley, G. C., Crouch, P. E., & Yamaguchi, G. T. (1993). Attributes of engineering graduates and their impact on curriculum design. *Journal of Engineering Education*, *82*(4), 203–211.

Felder, R. M., & Brent, R. (2004). The intellectual development of science and engineering students. Part 1: Models and challenges. *Journal of Engineering Education*, *93*(4), 269–277.

Felder, R. M., Felder, G. N., & Dietz, E. J. (1998). A longitudinal study of engineering student performance and retention. V. Comparisons with traditionally-taught students. *Journal of Engineering Education*, *87*(4), 469–480.

Finelli, C. J., Bergom, I., & Mesa, V. (2011). Student Teams in the Engineering Classroom and Beyond: Setting up Students for Success. CRLT Occasional Paper No. 29. *Center for Research on Learning and Teaching*.

Fisher, D., & Frey, N. (2013). *Better learning through structured teaching: A framework for the gradual release of responsibility*. ASCD.

Gallegos, P. J., & Peeters, J. M. (2011). A measure of teamwork perceptions for team-based learning. *Currents in Pharmacy Teaching and Learning*, *3*(1), 30–35.

Garmendia Mujika, M., Garikano Osinaga, X., Sierra Uria, E., & Perez Manso, A. (2013). Developing teamwork efficacy factors: An experience in a project based learning context. *International Journal of Engineering Education*, *29*(3), 752–762.

Ge, X., & Land, S. M. (2003). Scaffolding students' problem-solving processes in an ill-structured task using question prompts and peer interactions. *Educational Technology Research and Development*, *51*(1), 21–38.

Giannakos, M. N., Divitini, M., & Iversen, O. S. (2017). Entertainment, engagement, and education: Foundations and developments in digital and physical spaces to support learning through making. *Entertainment Computing*, *21*. https://doi.org/10.1016/j.entcom.2017.04.002

Giannakos, M. N., Divitini, M., Iversen, O. S., & Koulouris, P. (2015). Making as a pathway to foster joyful engagement and creativity in learning. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* (Vol. 9353). https://doi.org/10.1007/978-3-319-24589-8_58

Gibson, W., & Brown, A. (2009). *Working with qualitative data*. Sage.

Goldman, S., Kabayadondo, Z., Royalty, A., Carroll, M. P., & Roth, B. (2014). Student teams in search of design thinking. In *Design Thinking Research* (pp. 11–34). Springer.

Goldman, S., & Zielezinski, M. B. (2016). Teaching with Design Thinking: Developing New Vision and Approaches to Twenty-First Century Learning. In *Connecting Science and Engineering Education Practices in Meaningful Ways* (pp. 237–262). Springer.

Gully, S. M., Incalcaterra, K. A., Joshi, A., & Beaubien, J. M. (2002). A meta-analysis of team-efficacy, potency, and performance: interdependence and level of analysis as moderators of observed relationships. *Journal of Applied Psychology*, *87*(5), 819.

Hackman, J. R. (1990). *Groups that work and those that don't*. Jossey-Bass.

Halverson, E. R., & Sheridan, K. (2014). The maker movement in education. *Harvard Educational Review*, *84*(4), 495–504.

Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *American Journal of Physics*, *60*(7), 637–644.

Hira, A., Joslyn, C. H., & Hynes, M. M. (2015). Classroom makerspaces: Identifying the opportunities and challenges. In *Proceedings - Frontiers in Education Conference, FIE* (Vol. 2015-February). https://doi.org/10.1109/FIE.2014.7044263

Hutchison, M. A., Follman, D. K., Sumpter, M., & Bodner, G. M. (2006). Factors influencing the self-efficacy beliefs of first-year engineering students. *Journal of Engineering Education*, *95*(1), 39–47.

Johnson, B., & Ulseth, R. (2017). Student experience for the development of professional competencies in a project-based learning curriculum. *The International Journal of Engineering Education*, *33*(3), 1031–1047.

Jonassen, D. (1997). Instructional design models for well-structured and III-structured problem-solving learning outcomes. *Educational Technology Research and Development*, *45*(1), 65–94.

Jonassen, D., Strobel, J., & Lee, C. B. (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal of Engineering Education*, *95*(2), 139–151.

Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika*, *39*(1), 31–36.

Kasl, E., Marsick, V. J., & Dechant, K. (1997). Teams as learners: A research-based model of team learning. *The Journal of Applied Behavioral Science*, *33*(2), 227–246.

Kerr, B. (2015). The flipped classroom in engineering education: A survey of the research. In *2015 International Conference on Interactive Collaborative Learning (ICL)* (pp. 815–818). IEEE.

Klein, M. (1993). Supporting conflict management in cooperative design teams. *Group Decision and Negotiation*, *2*(3), 259–278.

Knight, D. W., Carlson, L. E., & Sullivan, J. F. (2003). Staying in engineering: Impact of a hands-on, team-based, first-year projects course on student retention. *Age*, *8*, 1.

Kozlowski, S. W. J., & Bell, B. S. (2008). Team learning, development, and adaptation. *Group Learning*, 15–44.

Kozlowski, S. W. J., & Ilgen, D. R. (2007). The science of team success. *Scientific American Mind*, *18*(3), 54–61.

Lamm, M. H., Dorneich, M., & Rover, D. T. (2014). Team-based learning in engineering classrooms: feedback form and content adds value to the learning experience.

Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. *Learning in Doing*. https://doi.org/10.2307/2804509

Lee, C., Tinsley, C. H., & Bobko, P. (2002). An Investigation of the Antecedents and Consequences of Group-Level Confidence 1. *Journal of Applied Social Psychology*, *32*(8), 1628–1652.

Lenhart, C., Bouwma-Gearhart, J., Villanueva, I., Youmans, K., & Nadelson, L. S. (2020). Engineering faculty members' perceptions of university makerspaces: Potential affordances for curriculum, instructional practices, and student learning. *International Journal of Engineering Education*, *36*(4).

Lent, R. W., Brown, S. D., & Hackett, G. (1994). Toward a unifying social cognitive theory of career and academic interest, choice, and performance. *Journal of Vocational Behavior*, *45*(1), 79–122.

Lent, R. W., Schmidt, J., & Schmidt, L. (2006). Collective efficacy beliefs in student work teams: Relation to self-efficacy, cohesion, and performance. *Journal of Vocational Behavior*, *68*(1), 73–84.

Levine, R. E. (2012). Peer evaluation in team-based learning. *Team-Based Learning for*

Health Professions Education: A Guide to Using Small Groups to Improve Learning, 103–116.

Lingard, R. W. (2010). Teaching and assessing teamwork skills in engineering and computer science. *Journal of Systemics, Cybernetics and Informatics*, *18*(1), 34–37.

Lönngren, J. (2017). *Wicked problems in engineering education: preparing future engineers to work for sustainability*. Chalmers University of Technology.

Loughry, M. L., Ohland, M. W., & DeWayne Moore, D. (2007). Development of a theory-based assessment of team member effectiveness. *Educational and Psychological Measurement*, *67*(3), 505–524.

Loughry, M. L., Ohland, M. W., & Woehr, D. J. (2014). Assessing teamwork skills for assurance of learning using CATME team tools. *Journal of Marketing Education*, *36*(1), 5–19.

Mahn, H. (1999). Vygotsky's methodological contribution to sociocultural theory. *Remedial and Special Education*, *20*(6), 341–350.

Martin, L. (2015). The promise of the maker movement for education. *Journal of Pre-College Engineering Education Research (J-PEER)*, *5*(1), 4.

Mathieu, J., Maynard, M. T., Rapp, T., & Gilson, L. (2008). Team effectiveness 1997-2007: A review of recent advancements and a glimpse into the future. *Journal of Management*, *34*(3), 410–476.

Michaelsen, L. K., Davidson, N., & Major, C. H. (2014). Team-Based Learning Practices and Principles in Comparison With Cooperative Learning and Problem-Based Learning. *Journal on Excellence in College Teaching*, *25*.

Michaelsen, L. K., Knight, A. B., & Fink, L. D. (2002). *Team-based learning: A transformative use of small groups*. Greenwood publishing group.

Michaelsen, L. K., & Sweet, M. (2008). The essential elements of team-based learning. *New Directions for Teaching and Learning*, *2008*(116), 7–27.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2018). *Qualitative data analysis: A methods sourcebook*. Sage publications.

Mills, J. E., & Treagust, D. F. (2003). Engineering education—Is problem-based or project-based learning the answer. *Australasian Journal of Engineering Education*, *3*(2), 2–16.

Mott, J., & Peuker, S. (2015). Achieving high functioning teams using team based learning in flipped classrooms. *Age*, *26*, 1.

Najdanovic-Visak, V. (2017). Team-based learning for first year engineering students. *Education for Chemical Engineers*, *18*, 26–34.

National Science Foundation. (2018). *Science and Engineering Indicators 2018 (NSB-2018-01)*. Washinton, DC.

Newstetter, W. C., & Svinicki, M. D. (2015). Learning theories for engineering education practice. In *Cambridge Handbook of Engineering Education Research*. https://doi.org/10.1017/CBO9781139013451.005

Oakley, B. A., Hanna, D. M., Kuzmyn, Z., & Felder, R. M. (2007). Best practices involving teamwork in the classroom: Results from a survey of 6435 engineering student respondents. *IEEE Transactions on Education*, *50*(3), 266–272.

Oakley, B., Felder, R. M., Brent, R., & Elhajj, I. (2004). Turning student groups into effective teams. *Journal of Student Centered Learning*, *2*(1), 9–34.

Ohland, M. W., Loughry, M. L., Woehr, D. J., Bullard, L. G., Felder, R. M., Finelli, C. J., … Schmucker, D. G. (2012). The comprehensive assessment of team member effectiveness: Development of a behaviorally anchored rating scale for self-and peer evaluation. *Academy of Management Learning & Education*, *11*(4), 609–630.

Pajares, F. (1996). Self-efficacy beliefs in academic settings. *Review of Educational Research*, *66*(4), 543–578.

Papert, S. A. (1975). Teaching children thinking. *Journal of Structural Learning*, *4*, 219–229.

Passow, H. J., & Passow, C. H. (2017). What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review. *Journal of Engineering Education*, *106*(3). https://doi.org/10.1002/jee.20171

Peppler, K., & Bender, S. (2013). Maker movement spreads innovation one project at a time. *Phi Delta Kappan*, *95*(3), 22–27.

Pfaff, E., & Huddleston, P. (2003). Does it matter if I hate teamwork? What impacts student attitudes toward teamwork. *Journal of Marketing Education*, *25*(1), 37–45.

Piaget, J. (1972). Intellectual evolution from adolescence to adulthood. *Human Development*, *15*(1), 1–12.

Prince, M. J., & Felder, R. M. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of Engineering Education*, *95*(2), 123–138.

Razzouk, R., & Shute, V. (2012). What is design thinking and why is it important? *Review of Educational Research*, *82*(3), 330–348.

Rhee, J., Parent, D., & Basu, A. (2013). The influence of personality and ability on undergraduate teamwork and team performance. *SpringerPlus*, *2*(1), 1–14.

Richard, G., & Giri, S. (2017). Inclusive collaborative learning with multi-interface design: Implications for diverse and equitable makerspace education. Philadelphia, PA: International Society of the Learning Sciences.

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*(2), 155–169.

Rittel, H., & Webber, M. (1972). Wicked Problems in Cross, N. *1974) Man-Made*

Futures The Open University/Hutchinson London, 272–280.

Ruiz, B., & Adams, S. (2003). Attitudes Toward Teamwork and Team Effectiveness in Higher Education. *Age*, *8*, 1.

Ruiz Ulloa, B. C., & Adams, S. G. (2004). Attitude toward teamwork and effective teaming. *Team Performance Management: An International Journal*, *10*(7/8), 145–151.

Saorín, J. L., Melian-Díaz, D., Bonnet, A., Carbonell Carrera, C., Meier, C., & De La Torre-Cantero, J. (2017). Makerspace teaching-learning environment to enhance creative competence in engineering students. *Thinking Skills and Creativity*, *23*. https://doi.org/10.1016/j.tsc.2017.01.004

Seering, W. (2009). A curriculum that meets the customers' needs. In *invited talk at the NSF-sponsored workshop "Implementing the Recommendations of 5xME*.

Seymour, E., & Hewitt, N. M. (1997). Talking About Leaving: Why Undergraduates Leave the Sciences. Boulder, Colorado. Westview Press.

Shapiro, E. J., & Dempsey, C. J. (2008). Conflict resolution in team teaching: A case study in interdisciplinary teaching. *College Teaching*, *56*(3), 157–162.

Sheppard, S., Colby, A., Macatangay, K., & Sullivan, W. (2007). What is engineering practice? *International Journal of Engineering Education*, *22*(3), 429.

Sheppard, S. D. (2003). A description of engineering: An essential backdrop for interpreting engineering education. In *Proceedings (CD), Mudd Design Workshop IV*. Harvey Mudd College.

Sheppard, S. D., Macatangay, K., Colby, A., & Sullivan, W. M. (2009). Educating engineers: Designing for the future of the field. 2009. *Stanford, CA: Jossey-Bass. Age*, *25*, 18.

Sheppard, S., Gilmartin, S., Chen, H. L., Donaldson, K., Lichtenstein, G., Eris, O., … Toye, G. (2010). Exploring the Engineering Student Experience: Findings from the Academic Pathways of People Learning Engineering Survey (APPLES). TR-10-01. *Center for the Advancement of Engineering Education (NJ1)*.

Sheridan, K., Halverson, E. R., Litts, B., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review*, *84*(4), 505–531.

Shulman, L. S., & Wilson, S. M. (2004). *The wisdom of practice: Essays on teaching, learning, and learning to teach*. Jossey-Bass.

Simon, H. A. (1996). *The sciences of the artificial*. MIT press.

Stajkovic, A., & Lee, D. (2001). A meta-analysis of the relationship between collective efficacy and group performance. In *national Academy of Management meeting*.

Stajkovic, A., Lee, D., & Nyberg, A. J. (2009). Collective efficacy, group potency, and group performance: Meta-analyses of their relationships, and test of a mediation model. *Journal of Applied Psychology*, *94*(3), 814.

Swail, W. S. (2003). *Retaining Minority Students in Higher Education: A Framework for Success. ASHE-ERIC Higher Education Report. Jossey-Bass Higher and Adult Education Series*. ERIC.

Tashakkori, A., & Teddlie, C. (2010). Sage handbook of mixed methods in social & behavioral research. sage.

Tesluk, P. E., & Mathieu, J. E. (1999). Overcoming roadblocks to effectiveness: Incorporating management of performance barriers into models of work group effectiveness. *Journal of Applied Psychology*, *84*(2), 200.

Tretter, T. R., Jones, M. G., Andre, T., Negishi, A., & Minogue, J. (2006). Conceptual boundaries and distances: Students' and experts' concepts of the scale of scientific phenomena. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *43*(3), 282–319.

Veenstra, C. P., Dey, E. L., & Herrin, G. D. (2009). A Model for Freshman Engineering Retention. *Advances in Engineering Education*, *1*(3), n3.

Vossoughi, S., & Bevan, B. (2014). Making and tinkering: A review of the literature. *National Research Council Committee on Out of School Time STEM*, 1–55.

Vossoughi, S., Hooper, P. K., & Escudé, M. (2016). Making Through the Lens of Culture and Power: Toward Transformative Visions for Educational Equity. *Harvard Educational Review*, *86*(2). https://doi.org/10.17763/0017-8055.86.2.206

Vygotsky, L. (1960). Razvitie vysshikh psikhicheskikh funktsii [Development of the higher mental functions]. *Moscow: APN*.

Vygotsky, L. (1978). Mind in society: The development of higher mental process. Cambridge, MA: Harvard University Press.

Vygotsky, L. (1981). The instrumental method in psychology. *The Concept of Activity in Soviet Psychology*, 135–143.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard university press.

Wenger, E. (1998). Communities of practice: Learning, meaning, and identity. *New York: Cambridge*.

Wertsch, J. V. (1985). *Vygotsky and the social formation of mind*. Harvard University Press.

Wertsch, J. V. (1991). A sociocultural approach to socially shared cognition.

Wilczynski, V., & Adrezin, R. (2016). Higher education makerspaces and engineering education. *American Society of Mechanical Engineers, Phoenix, Arizona*.

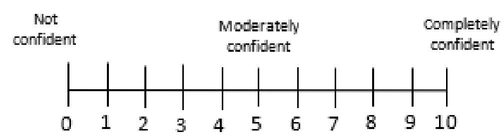
Yu, S. (2016). Makerspaces as learning spaces: An historical overview and literature review.

Appendix A

Student Teamwork Perceptions Survey – PRE, MID, POST

PART 1. <u>How confident</u> are you that your engineering design team could…

a. Reach agreement about what needs to get done at each meeting.
b. Find ways to bridge individual differences between team members.
c. Assist members who are having difficulty with certain tasks.
d. Develop a workable project design in a reasonable amount of time.
e. Communicate well with one another despite differences in background.
f. Adapt to changes in group tasks or goals.
g. Work well together even in challenging situations.
h. Deal with feedback or criticism from course instructors or GTAs.
i. Find ways to capitalize on the strengths of each member.



<u>PART 2. Rank the following</u> characteristics of team effectiveness from (1) most to (6) least important.

a. Communicates clearly.
b. Establishes a common purpose/goal(s).
c. Ability to resolve conflict.
d. Accountable individuals [to the team] (every person does what they say they will).
e. Every individual has clearly defined roles/tasks.
f. Every individual is supported and is confident in sharing their own ideas.

	Ranking
Most important	
Least important	

Appendix B

Peer Evaluations of Team Member Effectiveness

Modified from: (Loughry et al., 2014) Comprehensive Assessment of Team Member Effectiveness (CATME) instrument.

Dimension 1: Contributing to the team's work.

	Teammate #1	Teammate #2	Teammate #3	Behavioral Ratings
Contributing to the teams work	5	5	5	• Does more or higher-quality work than expected. • Makes important contributions that improve the team's work. • Helps to complete the work of teammates who are having difficulty.
	4	4	4	*Demonstrates behaviors described in both 3 and 5.*
	3	3	3	• Completes a fair share of the team's work with acceptable quality. • Keeps commitments and completes assignments on time. • Fills in for teammates when it is easy or important.
	2	2	2	*Demonstrates behaviors described in both 1 and 3.*
	1	1	1	• Does not do a fair share of the team's work. Delivers sloppy or incomplete work. • Misses deadlines. Is late, unprepared, or absent for team meetings. • Does not assist teammates. Quits is the work becomes difficult.

Dimension #2: Interacting with teammates.

	Teammate #1	Teammate #2	Teammate #3	Behavioral Ratings
Interacting with teammates	5	5	5	• Asks for and shows an interest in teammates' ideas and contributions. • Improves communication among teammates. Provides encouragement or enthusiasm to the team. • Asks teammates for feedback and uses their suggestions to improve.
	4	4	4	*Demonstrates behaviors described in both 3 and 5.*
	3	3	3	• Listens to teammates and respects their contributions. • Communicates clearly. Shares information with teammates. Participates fully in team activities. • Respects and responds to feedback from teammates.
	2	2	2	*Demonstrates behaviors described in both 1 and 3.*
	1	1	1	• Interrupts, ignores, bosses, or makes fun of teammates. • Take actions that affect teammates without their input. Does not share information. • Complains, makes excuses, or does not interact with teammates. Accepts no help or advice.

Dimension #3: Keeping the team on track.

	Teammate #1	Teammate #2	Teammate #3	Behavioral Ratings
Interacting with teammates	5	5	5	• Watches conditions affecting the team and monitors the team's progress. • Makes sure that teammates are making appropriate progress. • Gives teammates specific, timely, and constructive feedback.
	4	4	4	*Demonstrates behaviors described in both 3 and 5.*
	3	3	3	• Notices changes that influence the team's success. • Knows what everyone on the team should be doing and notices problems. • Alerts teammates or suggests solutions when the team's success is threatened.
	2	2	2	*Demonstrates behaviors described in both 1 and 3.*
	1	1	1	• Is unaware of whether the team is meeting its goals. • Does not pay attention to teammates' progress. • Avoids discussing team problems, even when they are obvious.

Dimension #4: Expecting quality.

	Teammate #1	Teammate #2	Teammate #3	Behavioral Ratings
Interacting with teammates	5	5	5	• Motivates the team to do excellent work. • Cares that the team does outstanding work, even if there is no additional reward. • Believes that the team can do excellent work.
	4	4	4	*Demonstrates behaviors described in both 3 and 5.*
	3	3	3	• Encourages the team to do good work that meets all requirements. • Wants the team to perform well enough to earn all available rewards. • Believes that the team can fully meet its responsibilities.
	2	2	2	*Demonstrates behaviors described in both 1 and 3.*
	1	1	1	• Satisfied even if the team does not meet assigned standards. • Wants the team to avoid work, even if it hurts the team. • Doubts that the team can meet its requirements.

Appendix C

GTA Rating of Team Effectiveness

Instructions provided to GTA:

Thinking about the teams in your class, please rate…

- *1: No evidence/indication.*
- *2: Minimal evidence/indication.*
- *3: Adequate evidence/indication.*

(5 indicators of teamwork effectiveness ratings)

1. The **amount of effort** the entire team put into the cornerstone project.
2. Your (GTA) impression of the **quality** of the team's overall effectiveness in the three aspects for the cornerstone project (i.e., written, designed, and presented).

For items 3-5, please consider by recalling your observations throughout the semester, how effective each student design team functioned in relation to the Cornerstone (final) Project:

3. Relating (**communicating**) with one another throughout the semester.
4. **Producing** a result.
5. **Managing** the process throughout the semester.

(Optional) Please comment for elaboration of a team rating or provide specific examples of teams/individual students that impacted a GTA rating.

Appendix D

Cornerstone Design Project

Class __________ **Team__________**

SCORE 1: 3-DIMENSIONAL PRINTED PART		
Criteria	**Points Possible**	**Points Awarded**
The team designed their own valid 3D printed part (as opposed to using a provided design)	13	
No extraneous materials used to meet design criteria (i.e., height modification, stability, etc.)	5	
The 3D printed part for the motor mount allows the windmill to function, driving the AC motor and powering an LED	8	
The part is fastened to the top of the nacelle using four 5” bolts	4	
The AC motor rests snug & secure on the 3D part and is fastened via two ½ x 8 x 32 screws/nuts	4	
The length and width of the part does NOT extend past the dimensions of the nacelle (up to 1/16” is acceptable)	4	
The windmill & AC motor shafts rotate in the SAME direction	4	
The 16-tooth gear is fastened to the AC motor shaft	4	
No modifications were made to nacelle or AC motor	4	
Tachometer mounting is legitimate (i.e. stable & aligned)	10	
Total Points	**60**	

SCORE 2: MICROPROCESSOR PROGRAMMING		
Criteria	**Points Possible**	**Points Awarded**
Tachometer mounting is stable & aligned	10	
LCD toggles display via pushbutton	10	
LCD displays reasonable rpm value(s)	4	
LCD displays reasonable power out value(s)	4	
LCD displays reasonable blade efficiency value(s)	4	
LCD displays reasonable motor efficiency value(s)	4	
LCD displays reasonable system efficiency value(s)	4	
Total Points	**40**	

Appendix E

Cornerstone Technical Writing Report Rubric

	Elements of the Written Report		
	Overall composition score	*Technical document formatting*	*Cornerstone Project Design description and content*
Categories for each element	• Title page • Table of contents • 3D Printed Parts • Building the Windmill • Mechanical Experiments • Critical Thinking • Gannt Chart • 3D Printed Parts, drawings • LCD Code	• Document formatted correctly • Headings are appropriate • Tables, Figures, and Equations are used correctly	• Title • Design Process • Methodology • Results • Conclusion • 3 examples of Critical Thinking
Points	**30**	**30**	**40**
Total Points	**100**		

CURRICULUM VITA

Teresa L. Tinnell
University of Louisville

Louisville, KY 40292

Email: terri.tinnell@louisville.edu

EDUCATION

University of Louisville August 2021
Ph.D. Curriculum and Instruction, STEM Education

University of Louisville May 2010
M.A. in Teaching, Middle & Secondary Education
Teaching Certifications: Mathematics & Physics, grades 8-12

University of Louisville May 2008
B.A. in Mathematics, minor: Physics

TEACHING EXPERIENCE

University of Louisville Louisville, KY
Instructor, Department of Elementary, Middle, & Secondary Education 2019-2020

Arvin Education Center, Oldham County Public Schools Buckner, KY
Engineering Academy Department Chair, Math & Engineering Teacher 2014-2016

Bellarmine University, KY Governor's Scholar Program Louisville, KY
Physical Science Faculty & Seminar Instructor Spring 2014-2015

Martha Layne Collins High School, Shelby County Public Schools Shelbyville, KY
Engineering Pathway Lead, STEM Teacher 2010-2014

PROFESSIONAL EXPERIENCE

J.B. Speed School of Engineering, University of Louisville Louisville, KY
Graduate Research Assistant 2016-2021

- Liaison and mentor facilitating collaboration of College of Education and Human Development and the Speed School of Engineering faculty.

Junior Science & Humanities Symposium Louisville, KY
Project Director, U.S. Department of Defense, National Science Teacher Association 2017-2021

Youth for Technology Louisville, KY
STEM Programs Lead, Measurement & Evaluation Director, Volunteer 2017-2021

Project Lead The Way Indianapolis, IN
Master Teacher, Principles of Engineering 2013-2016

General Electric Mount Vernon, IN
Engineering Project Manager, Lexan© Division 2006-2008

JOURNAL PUBLICATIONS

Tinnell, T., Zhong, J., Tretter, T., & Ralston, P. (2021). Efficacy of an Education Research Workshop Series for STEM-H Faculty. *Cogent Education*

Tinnell, T., Campbell, L., & McGinley, M. (pending). *Concrete Chemistry*. Science Teacher, National Association of Science Teachers.

McFadden, J., **Tinnell, T.,** Trzaskus, M., Robinson, B., & Tretter, T. (2021). Enhancing K-8 Teachers' Capacity to Develop Multi-Dimensional, Formative Science Assessments: Assessing the Assessments. *School Science and Mathematics*.

Mark, S., **Tinnell, T.,** Constantin, G. & Alexander, O. (2021). It got me back to science: Arts-integrated science engagement for middle school girls. *Journal for Learning through the Arts*.

Tinnell, T., Ralston, P., Tretter, T., & Mills, M. (2019). Sustaining pedagogical change via Faculty Learning Community. *International Journal of STEM Education, 6(1), 1-16*.

Tinnell, T., Tretter, T., Thornburg, W., & Ralston, P. (2019). Successful interdisciplinary collaboration: Supporting science teachers with a systematic, on-going, intentional collaboration between university engineering and science teacher education faculty. *Journal of Science Teacher Education, 30(6).*

CONFERENCE PROCEEDINGS & PRESENTATIONS

Tinnell, T., Honken, N., & Ralston, P. (2020). ACT/SAT preparation and the percent of variability in first year engineering student GPA explained by ACT/SAT scores. In *Proceedings of the 127th ASEE Annual Conference and Exposition*. Virtual On-line. June 21-24, 2020.

Zhong, Z., Ralston, P., **Tinnell, T.,** & Tretter, T. (2020). Designing a Streamlined Workshop for STEM-H Faculty Engaged in the Scholarship of Teaching and Learning. In *Proceedings of the 127th ASEE Annual Conference and Exposition*. Virtual On-line. June 21-24, 2020.

Lewis, J., Robinson, B., Hawkins, N., & **Tinnell, T.** (2020). Addressing First-Year Interest in Engineering via a Makerspace-Based Introduction to Engineering Course. In *Proceedings of the 127th ASEE Annual Conference and Exposition*. Virtual On-line. June 21-24, 2020.

Tinnell, T., Bego, C., Ralston, P., & Hieb, J. (2019). An interdisciplinary research group's collaboration to understand first-year engineering retention. In *Proceedings of the 126th ASEE Annual Conference and Exposition*. Tampa, FL. June 15-19, 2019.

Tinnell, T., Ralston, P., & Tretter. T. (2019). Faculty embracing collaborative learning techniques: Sustaining pedagogical change. In *Proceedings of the 126th ASEE Annual Conference and Exposition*. Tampa, FL. June 15-19, 2019.

Tinnell, T., Mark, S., Alexander, O., & Constantin, G. (2019). It got me back to science: arts-integrated science engagement for middle school girls. In Proceedings of the 92nd Annual International Conference. Baltimore, MD. March 31-April 3, 2019.

McFadden, J., Trzaskus, M., **Tinnell, T.,** Robinson, B., & Tretter, T. (2019). Tracking the quality of classroom-embedded, formative assessments in the era of NGSS. In *Proceedings of the 92nd Annual International Conference*. Baltimore, MD. March 31-April 3, 2019.

Tinnell, T. & McNeil, J. (2017). First-year students' definitions of engineering. In *Proceedings of the 124th ASEE Annual Conference and Exposition*. Columbus, OH. June 15-19, 2019.

GRANT WORK

Co-PI, *U.S. Dept. of Defense Tri-Services, NSTA, Award: $10,000* Jan. 2020
Teacher and Researcher Network to Advance STEM Research among high school students

Co-PI, *U.S. Dept. of Defense Tri-Services, NSTA, Annual Award: $10-14,000* 2017-2021
Junior Science & Humanities Symposium, KY & IN Regions

PI, *Kentucky Department of Education, Awards: $25,000 & $50,000* 2013-2014
Energy Pipeline & Energy Technology for Grades 8-12

PI, *KY Girls STEM Collaborative, Award: $2,500* 2012
Girls in Engineering, Math, and Science (GEMS) Mini-Grant

SERVICE AND PROFESSIONAL DEVELOPMENT

Doctoral Student Representative, President's Strategic Plan, Learn Subcommittee 2020-current

Director of Graduate Student Travel, Graduate Student Council Executive Board 2019-2020

Department Representative, Graduate Student Council 2017-2021

Peer Reviewer, International Journal for STEM Education 2019-current

Advisory Board, Oldham County Public Schools, Engineering Academy 2018-current

Reviewer, American Society of Engineering Education 2016-current

K-5 Teacher Trainer, KY Elementary Engineering and Robotics initiative 2012-2015

PROFESSIONAL AFFILIATIONS

American Society of Engineering Educators (ASEE)

National Science Teachers Association (NSTA)

Association for Science Teacher Education (ASTE) & Mid-Atlantic Association for Science Teacher Education (MASTE)

American Educational Research Association (AERA)

Kappa Delta Pi Education Honor Society

NOTABLE AWARDS

Teacher of the Year, Martha Layne High School, Shelbyville, KY 2014

Science Student Teacher of the Year, University of Louisville, College of Education & Human Development 2010