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Ten Teamwork Findings from Student Design Teams*

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Given the increasing emphasis on teamwork in engineering education, our interdisciplinary research team has combined expertise in the science of teamwork and best practices in engineering education, spending three years investigating the functioning of engineering design teams at our university. This effort has culminated in a number of research efforts incorporating both qualitative and quantitative techniques as well as cutting-edge analytical methods. This paper seeks to summarize our findings, highlighting strengths and drawbacks of these methods and providing ten student engineering team findings that have emerged from our research in order. Our findings thus far, centered on topics such as team leadership, diversity, psychological safety, and performance, have provided novel insights within our institution, but also advance the science of teamwork and engineering education. Accordingly, we shed light not only on the implications of our findings for engineering education, but also on the types of findings that might be elicited through various approaches to teamwork assessment in engineering education.

Keywords: teamwork; teamwork assessment; methodological approaches

1. Introduction

In recent decades, the emphasis on teamwork in engineering from organizations and accreditation agencies alike has driven a desire for educational institutions to better understand the functioning and development of teams in a university setting [1, 2]. Toward this effort, our interdisciplinary research team has combined expertise in the science of teamwork with engineering education to spend three years investigating teamwork in engineering design courses at our university via a number of research efforts. Our studies have covered many unique topics using innovative methods and analytical approaches. This paper seeks to summarize our findings, highlighting strengths and drawbacks of the various methods taken by our research team. In addition, we provide ten student engineering team findings that have emerged from our research in order to shed light on the types of findings that might be elicited through various approaches to assessment.

Our paper begins by describing the methodologies used toward this effort, including qualitative, quantitative, and longitudinal work across both large and small samples. We have drawn from survey-based quantitative methods to investigate phenomena at the individual, dyad, and team level over time. In addition, we have used ethnographic and grounded theory qualitative approaches to examine teamwork processes in cross-cultural teams and to better understand the experiences of women as they transfer what they have learned in their engineering design courses to their early careers. We then share how these varied approaches have provided insight on a number of engineering team phenomena, specifically around team leadership, diversity, psychological safety, and performance.

2. Study Overviews

In the past three years, members of our research team have conducted a number of dissertations, theses, and research projects supervised by the last author in an ongoing effort to improve teamwork in undergraduate engineering teams at our university. These research studies were not conducted to understand a single phenomenon, and were independent studies not intended to build directly off of each

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other. Rather, the studies were projects led by members of our research team in an attempt to explore a variety of questions. In this article, we attempt to synthesize the cumulative findings from these projects. We emphasize that the findings of these studies have not been published elsewhere, and our integration is intended to provide a more concrete set of findings for engineering education researchers. To provide a frame of reference for the following sections, we outline the projects conducted thus far.

2.1 Zajac, 2017

In the first of such efforts, Zajac [3–7] conducted a longitudinal, ethnographic study of engineering design teams throughout a 7-week engineering internship at our university. These student design teams were cross-cultural, including members from Brazil, Malawi, and the United States, and the students worked on real-world projects that were in various stages of development. The central research questions in this study surrounded how engineering design teams communicate and make decisions cross-culturally, though the inductive study design lent itself to the generation of additional themes.

While the study primarily drew from qualitative methods, quantitative surveys were occasionally incorporated, ensuring a robust mixed-methods design [8]. Researchers conducted weekly interviews with each of the 13 participants; collected field notes via frequent team observations; and assessed students via surveys on team orientation [9], personality, culture [10], performance, skill inventories, and prototype evaluation forms. Data analysis for this project involved a grounded theory approach [11], in which the researchers coded interview data and incorporated observational data to develop a theoretical model representing communication in cross-cultural teams.

2.2 Lacerenza, 2017

In contrast to Zajac [3], Lacerenza's [12] study was survey-based and quantitative, though it shared its longitudinal design. The central research questions of this study focused on the predictors of leader emergence and effectiveness in teams, specifically investigating the role of students' grit [13], assertiveness [14], technical competence, and personality in predicting leader emergence [15, 16].

This study included two samples of students in semester-long engineering design courses. The first sample (N = 13) included first year engineering students working in 3 teams, whereas the second sample (N = 48) included senior-level participants working in 9 teams. In both samples, teams were assigned clients to engage in real-world projects. Over the course of the semester (or two semesters, in the case of senior design teams), the teams are responsible for working with the assigned client to identify their needs and develop, build, and analyze a product prototype that addresses their issue. Students completed surveys at three time points throughout the semester to allow our research team to assess outcomes longitudinally, and to more proximally infer causality in the study's outcomes.

Data analysis was conducted using multilevel modelling, which will be discussed in depth later in this manuscript. This technique allows researchers to account for nested data. In this case, multilevel modelling was used to account for students nested within their teams, as individual-level variables (e.g., leader emergence) are dependent on team-level variables (e.g., team demographic diversity). In this way, we were able to examine individual outcomes while accounting for students' teams.

2.3 Marlow, 2018

Though the study design of this project was similar in many ways to Lacerenza's [12] approach, the central research questions varied. Specifically, this project focused on the impact of team personality on psychological safety [17] within teams. Marlow [18] surveyed 26 senior-level engineering design teams, again working on real-world engineering design projects, longitudinally at three time points during one semester. Instead of multilevel modelling, as the constructs of interest in this study was at the team level, we aggregated all constructs to the team level and conducted less complex multiple regression to test hypotheses.

2.4 Traylor & Croitoru, 2019

Finally, our work conducted over the past year has taken a multi-method approach to understand how working in teams impacts individuals, and specifically women and under-represented minorities, working in these teams [19]. This study was mixed-methods, involving two separate phases of data collection to allow for both generating theory regarding how women's self-efficacy and career aspirations develop as a function of their experiences working in engineering design teams.

In the first phase of the project, we interviewed women alumni (N = 21) from engineering subdisciplines including chemical engineering, bioengineering, mechanical engineering, civil engineering, electrical engineering, and computer science. Participants were interviewed regarding their experiences working in diverse groups, particularly instances in which they questioned their engineering skills or potential to excel in the field. This phase of the study again used a grounded theory approach to data analysis [11], involving coding all interview data.

In the second phase of this project, we conducted a semester-long, longitudinal study of engineering design students (N = 143) nested in 34 teams, providing group members with monthly, round-robin surveys to measure variables including incivility from the team generally and from each of its members [20], conflict [21], and outcome measures such as engineering confidence and self-efficacy [22].

3. Methodological Approaches

As alluded to in the previous section, a number of methodological approaches have driven our research questions forward. To provide engineering educators with an understanding of how various methodological approaches can be applied to specific research questions as well as the challenges that arose with various types of data collection, we provide an overview of the approaches used in our research. As we discuss in our mixed-methods section, in a number of cases we drew from multiple approaches to address our research questions. This section is not intended to provide a second overview of the studies, but rather to provide an overview of the types of methods we drew from to generate our findings.

3.1 Qualitative and Mixed-Method Approaches

Our studies have drawn from a number of qualitative and mixed method approaches, though the method, analyses, and data sources have varied somewhat depending on our research questions. Although our team primarily drew from quantitative methods, we used qualitative and mixed-methods studies to investigate complex phenomena and to obtain a rich account of teamwork processes even with small sample sizes. For example, Zajac's [3] study of cross-cultural teams warranted these approaches as understanding the impact of culture on team development and team processes is extremely complex. Designing a quantitative study on the same topic would require incredibly frequent surveys of team members and in this case, an ethnographic approach to the qualitative portion of the study provided a richer account of team processes. In addition, given that the number of teams in this study was quite small, a longitudinal and mixed-methods approach with multiple data sources allowed for an in-depth, rich account of these phenomena whereas findings from a quantitative study would have been limited due to low statistical power.

In our mixed methods approaches, data were triangulated to better understand and validate research findings. For example, Zajac's [3] approach drew from both qualitative interviews as well as quantitative surveys. Data were triangulated such that survey data were used to inform the ethnographic analysis. For example, Zajac [3] collected data on teammates' technical expertise – this information was used in the interpretation of observations and video recordings of teams as they made decisions. While interview data in this study were used to understand participants' psychological interpretations of their team experiences, video recordings and observation notes were used to see, objectively, the dynamic behaviors of teammates.

Though Traylor and Croitoru [19] and Lacerenza [12] drew from some ethnographic methods, Zajac's [3] study was the most closely aligned with a true ethnographic approach. Ethnographic research is a qualitative methodological approach using interviews, observation, video recordings, and potentially other archival data sources to unpack phenomena. Ethnographic approaches involve immersing oneself in the data, and even potentially joining in as a participant to understand the processes under question. Toward this effort, Zajac [3] used a number of data sources including interviews with participants, observations, and video recordings, to become fully immersed in the 7-week engineering design experience.

This ethnographic approach was particularly conducive to answering Zajac's [3] primary research questions, which surrounded *how* diverse engineering design teams make decisions. Given that the sample was too small to conduct many statistical analyses, this ethnographic approach allowed our team to dig deeper into these research questions, and led to the development of a more robust set of themes and theoretical framework than a quantitative study could have elicited.

Indeed, most of our qualitative approaches have involved ethnographic elements in study design, our studies have primarily looked to grounded theory for data analysis [3, 19]. While ethnography generally describes a method for collecting qualitative data, grounded theory describes an approach to analyze qualitative data. A grounded theory approach to data analysis includes converting interview, observation, and sometimes video content to text so that data can be manually coded. This coding approach typically involves an iterative approach, including "first-order" coding that summarizes lines or phrases in text using the subjects' language and "second-order" coding that categorizes first-order codes in themes that are tied more closely to the theoretical literature [7].

In contrast, a pilot study to supplement Lacerenza [12] was conducted using the same sample used by Zajac [3]. Instead of a grounded theory approach to analyzing this interview data, however, Lacerenza [7] uses a method that converts qualitative transcripts for quantitative analysis. In this effort, our team used Linguistic Inquiry Word Count (LIWC) to assess interview data collected in our study of cross-cultural teams. LIWC involves using pre-validated dictionaries to count the frequency of certain types of words in an individual's speech [23]. In this case, our research team was interested in the number of assertive and "gritty" sounding words participants used in their interviews, and how these speech patterns related to leader emergence. Unlike a grounded theory approach to analysis, which is "purely" qualitative, LIWC allows researchers to quantify qualitative data by providing word counts, in this case allowing our research team to analyze descriptive statistics and basic correlations to draw conclusions about the data.

Finally, to analyze video data for Zajac's [3] study of culturally diverse engineering teams, we developed a behaviorally-anchored rating system to investigate a number of team behaviors. To create this rating system, we identified constructs of interest and then developed descriptions of high levels on a construct versus low levels. Next, we trained a team of research assistants to watch the videos and code the videos, rating each team member on the extent to which they demonstrated each trait in videos of team meetings. Videos were double coded by raters, and discrepancies in coding were resolved via discussion. The results of this video coding effort were able to be used both quantitatively by using multilevel modelling techniques and qualitatively integrated with other findings to supplement theories derived from interview and observational data.

3.2 Survey-Based Approaches

While our qualitative approaches have allowed us to take a deep dive into our research questions, our survey-based approaches have allowed us to quantitatively and statistically test theories to understand how they apply in the context of engineering education. In general, survey development involved a critical assessment of the research questions at hand to determine the survey format and content. Survey content selection was relatively straightforward. Our team worked to unpack the psychological constructs embedded in our research questions. For example, Marlow [18], was interested in how personality traits impact team psychological safety and performance. Thus, validated measures of personality traits and psychological safety were identified via a literature search and selected for inclusion in the survey.

While content development is relatively straightforward, survey format is typically more nuanced. Our surveys are typically designed in one or more of three formats: team-based, round robin, and individual-based. Each of these approaches allows us to address different types of research questions, and can incorporate different types of statistical analysis and aggregation of responses.

Team-based surveys, like those used by Marlow [18], allow us to understand team-level phenomena. In this effort, we were specifically interested in psychological safety, a team-level construct, as an outcome variable. These types of surveys ask students questions about their team – for example, "How often do you and your teammates disagree about tasks?" While responses to these questions can be analyzed at the individual level, our team frequently aggregates responses to the team level to better understand how the group as a whole rates team-based constructs. In addition, intra-class correlation coefficients [24] can be used to examine the extent to which teammates agree about ratings of these constructs.

Round robin surveys ask students about their relationships with their teammates, and require specially designed surveys that allow students to enter the number and names of teammates to provide ratings for all teams. While this method comes with the added challenge of an extended length, the round robin format allows for flexibility in analysis. For example, Lacerenza [8] used round robin ratings to allow participants to nominate other teammates as team leaders, eventually using others' ratings to gain an individual-level of leader emergence for each participant as it was rated by their teammates. In contrast, Traylor and Croitoru [19] are using round robin surveys to assess information sharing within a team by asking participants how often their teammates share information with them. These data will be used to conduct social relations modeling [25] and network analysis [26], allowing us to understand team processes in engineering design more thoroughly.

Finally, our team frequently draws from individual-focused survey items to measure constructs such as personality and self-efficacy [e.g., 8, 18, 19]. Though individual-referent items can be aggregated to the team level, they can also be used to understand team functioning via multilevel modelling. For example, while Marlow [18] used individuals' personality assessments at the aggregate level as a measure of team performance, Traylor [27] uses this method to understand how self-efficacy develops in individuals as a function of their team experiences.

Survey-based approaches may also be improved through the use of CATME, the online survey-based tool that allows students to provide feedback to their teammates and feedback on their team experience overall. While our team has frequently used other survey-based platforms to distribute surveys, supplementing our analyses with data from CATME where applicable (and with IRB approval) has been instrumental in a deeper understanding of teamwork and to ensuring that students are not over-burdened with survey instruments.

3.3 Quantitative Analytical Methods

While the majority of our analytical methods are relatively straightforward (e.g., ANOVA, multiple linear regression), some of our work has drawn upon multilevel modeling and latent profile analysis to better understand engineering team functioning. Multilevel modelling, used in Lacerenza [8] as well as Traylor [27] allows for the analysis of data that is grouped. While traditional regression analyses assume that all variables are at the same "level" (e.g., individual level predictors and individual level outcomes), multilevel modelling allows researchers to assess the effect of team-level variables on individuals. For example, Traylor [27] focused on the development of self-efficacy and other variables for women in engineering teams. Multilevel modelling allowed our team to understand the effect of team-level variables on this individual-level outcome.

In addition to multilevel modelling, our team has drawn on latent profile analysis to understand engineering design team functioning. Latent profile analysis is considered a "team-centered" analytical method in that it categorizes teams based on a constellation of traits. For example, Croitoru [28] used latent profile analysis to determine what types of profiles of team conflict emerged in our sample of teams, identifying profiles with varying levels of task, relationship, and process conflict. This approach allowed us to better understand how profiles of conflict, rather than a simple composite, might differentially relate to important team outcomes.

4. Ten Findings from our Research

4.1 Finding 1: Team Cultural Diversity Influences Communication Within Design Teams

In our first foray into the integration of team science and engineering education, we sought to understand what affects the diversity-performance relationship in engineering design teams, focusing on cultural diversity, which has demonstrated to impact how engineering design teams function [29]. Through the previously described longitudinal, qualitative approach, Zajac [3] found that diversity dimensions led to both ineffective and effective communication behaviors, a finding that is in line with previous meta-analytic investigations of the relationship between team cultural diversity and communication [30]. The proposed theoretical model stemming from this work suggested that information flow in design teams via exchange, elaboration, and consideration, as well as a number of additional underlying behaviors influenced communication and subsequent performance. In addition, frequency, comprehension, equality, and timeliness were all identified as critical to successful communication in diverse teams.

This study also elicited findings related to the relationship between team diversity and team conflict, which plays an important role in team performance. Given that little research has investigated how group diversity influences conflict processes, this qualitative effort was able to surpass existing research by digging deeper into the phenomenon [30]. In initial stages of the design project, Zajac [3] found that team diversity led to diversity in conflict expression by comparing teams that reported team conflict early in the project with teams that did not report conflict. Specifically, results indicated that engineering teams attempting open conflict management did not experience a reduction in conflict. In addition engineering design by nature lends itself to more conflict than might occur in typical work teams. When teams used ineffective communication to communicate about their team conflict, subsequent relationship conflict continued to escalate throughout the course of the project.

4.2 Finding 2: Diversity-Based Intelligence can Influence the Extent to Which Engineering Design Team Members Draw from their Diverse Range of Expertise to Make Decisions

Though Zajac's [3] findings were primarily centered around overall team performance in demographically diverse teams, a subset of data for the project was used to investigate decision-making on the basis of a construct developed throughout the course of the study: diversity-based intelligence (DBI). This construct involves participants' demonstrated level of awareness, knowledge, and capabilities in regard to interacting with diverse others [5]. In order to understand how team differences in DBI impacted decision-making, researchers compared decision-making codes from the two teams with high collective and two with low collective DBI, analyzed data separately, and completed cross-case comparisons to assess the impact of DBI on decision-making.

In this study, we found that although members from all four teams reported frequently coming together to make team decisions, decision-making methods differed significantly between teams. Teams identified as low in DBI relied heavily on empirical evidence drawn from testing their products to make decisions. Conversely, teams demonstrating higher DBI were more likely to rely on others' opinions and were more comfortable with conflict as they determined whose ideas were best.

These findings were in line with the idea that individuals high in DBI might facilitate trust or higher psychological safety in teams, which could explain why these teams tended to discuss decisions beyond basic objective measures of success. Information coded for psychological safety seemed to support these findings, as members of high DBI teams more often mentioned instances of trust and psychological safety within their teams. Additionally, individuals high in DBI are more likely to be concerned with the perspectives of other team members, particularly from another culture. Rather than select entirely objective measures for decision-making, these teams place greater importance on the interpersonal aspects of decision-making. Again, the role of culture on team decision-making has received little attention in the literature, further emphasizing the importance of understanding these processes in culturally diverse teams [29].

4.3 Finding 3: Technical Competence, Grit, and Assertiveness Predict Leader Emergence in Engineering Design Teams

Lacerenza's [12] survey-based work investigated the relationship between predictor variables technical competence, grit, and assertiveness in relation to leader emergence. Though technical competence and assertiveness did not have an impact on leader emergence over time, all three of these variables impacted leader emergence halfway through the semester. These findings provided important implications for those individuals interested in becoming leaders within their engineering teams – while these characteristics are not entirely changeable, the extent to which students, for example, behave in an assertive manner may help them to establish a leadership role on their team early in the project. Previous research has established a relationship with surface-level characteristics, such as race and gender, with leader emergence; however, this study provided important implications for deeper-level characteristics in predicting leader emergence [15].

4.4 Finding 4: Perseverant Team Members Make the Most Effective Leaders in Engineering Design Teams

Upon further investigation, Lacerenza [12] found that individuals who demonstrated more grit made the most effective leaders over time. Although assertiveness and grit predicted leader emergence in the earlier stages of these engineering design projects, grit alone predicted leader emergence toward the end of these engineering design projects. It is expected that this pattern of results may have occurred because traits like assertiveness and technical competence, which are more readily ascertained by group members, are easier to judge earlier on and therefore members who display these traits are looked to as leaders in the early phases of the project.

4.5 Finding 5: Engineering Design Team Members with High Learning Orientation Tend to Emerge as Leaders

Marlow's [18] survey-based study also investigated leadership emergence, this time investigating the concept of learning goal orientation. Learning orientation, which describes an individual's propensity to focus on personal development and learning in goal-setting rather than performance [31], does not predict emergent leadership across all contexts. However, these findings indicate that within engineering design teams, learning goal orientation has a positive effect in perceptions of leadership. This may be because in the design context, individuals must be intrinsically motivated and interested in the learning process as much as the product, as too much focus on the product might be detrimental to the team's performance overall.

4.6 Finding 6: Effective Team Leadership Predicts Psychological Safety in Engineering Design Teams

Marlow's [18] study also examined team-level outcomes, specifically investigating psychological safety, which describes a team climate that is safe for interpersonal risk-taking [17]. Much of the work in organizational psychology and organizational behavior on this topic indicates that leaders play a vital role in predicting psychological safety in teams [32]. However, few studies of psychological safety investigate the role of emergent leaders in self-managed teams, instead looking at the role of formally appointed leaders in predicting psychological safety. Marlow's (2017) work indicated that effective team leadership did, indeed, predict psychological safety in the context of engineering design, further emphasizing the importance of leadership skills in undergraduate engineers.

4.7 Finding 7: Engineering Design Teams Characterized by Profiles High in Task Conflict and Low in Relationship Conflict Experience Higher Trust, Psychological Safety, and Team Performance

To better understand the dynamics of team conflict, particularly as it applies to an engineering context, Croitoru [28] used latent profile analysis to investigate team conflict as an antecedent to team trust, psychological safety, and team performance. This study provided support for a four-profile pattern of team conflict, involving two end-state profiles which included teams who were high in task conflict only

(TC dominant) or who were high in task, relationship, and process conflict (dysfunctional) and two mid-range profiles with moderate levels of all conflict.

Overall, we found that profiles high in task conflict but low in relationship conflict led to better team trust and team psychological safety and, to a lesser degree, to team performance. Though our work replicated a recent study by O'Neill and colleagues [21], conducting the study in our own sample provided an opportunity for learning about the unique features of our engineering design population. For example, though O'Neill's [21] study used undergraduate engineering teams, the students in the study completed four distinct projects over the course of a 13-week semester. Comparatively, our students were completing one project over the course of a summer, semester, or an entire year, and these students reported task conflict at much higher rates across the board than O'Neill's [21] teams. In this case, working to replicate and extend other research on undergraduate engineering teams elicited interesting findings catered to our own sample.

4.8 Finding 8: Team Experiences at the Undergraduate Level can Influence Individuals' Career Aspirations and Early Career Decisions

Shifting from a focus on team constructs to a focus on the individual's experience on a team, Traylor and Croitoru [19] conducted a qualitative study, interviewing early-career female engineers who attended our university (N = 21) in order to better understand how team-based experiences at the undergraduate level and in their workplaces impact early career outcomes.

Specifically, the findings of this study indicated that women experienced what we referred to as "subtle discrimination" through team-based processes, which occurred in some, but far from all of the teams our subjects described. The experiences shared with us indicated that undergraduate engineering design teams or immediate workgroups could both facilitate and impede feelings of inclusion and motivation to continue in engineering, demonstrating that teams have tremendous power in shaping women's experiences at work. For example, when describing a team experience that facilitated her desire to continue in engineering, one participant provided that, though she had initial difficulties working with one of her gender-diverse teams as an undergraduate, in the end the experience motivated her to continue in engineering. She shared that, ". . . we learned from each other's strengths and differences, and we fed off of it. We developed a system of communication that worked well for us . . . we were just very open and honest with each other, and we all had the same goal of doing the best we could on this project, which is why we worked out so well."

However, other participants had far less than positive experiences working on project teams. One participant provided that while working on a summer internship, "I was in an office surrounded by other white male engineers who would make comments like, 'Oh, things used to be so different before you and your boobs got here.' It was made clear that the rapport of this corner of the building had changed because I dared to be in that space as a woman. It was made abundantly clear to me, and I was made, essentially, to feel guilty about it." This experience ultimately led the participant to avoid similar working scenarios in the future, and she plans to begin a master's degree in a new field in the coming year to make a career pivot as a result of this negative experience.

4.9 Finding 9: Students' Engineering Belonging, Self-Efficacy, and Career Aspirations can Improve via Engineering Design Courses

Finally, our most recent work also centers around how experiences working on a team shape students' outcomes, but this time from a quantitative perspective. This survey-based project allowed us to understand how a number of variables important to student engineers' educational and career success: namely, engineering belonging, self-efficacy, and career aspirations [22]. Unsurprisingly, we found that students' engineering belonging, self-efficacy, and career aspirations increased significantly throughout the course of their semester in engineering design courses at both the freshman and senior level [23]. Previous work in this domain has indicated that factors like belonging and self-efficacy are vital predictors of persistence in engineering [33, 34].

4.10 Finding 10: Teams Play an Important Role in Students' Experiences in Engineering Design Courses

This study also provided compelling evidence that the teams in which students work play an important role in their experiences in engineering design courses. Using multilevel modelling, we were able to isolate the variance in engineering belonging, self-efficacy, and career aspirations that could be explained by the team in which a student worked. We found that students' teams explained a significant proportion of the variance in the development of their engineering belonging, self-efficacy, and career aspirations throughout the course of the semester [23]. Though individual- or class-level features also play some role in explaining the development of these traits, these findings provide an impetus for better understanding teamwork in engineering education.

5. Limitations and Directions for Future Research Teams

Over the course of three years, our team has learned a number of important lessons for engaging in interdisciplinary research and assessment of engineering teams. Indeed, none of our studies were perfect – but together, they provide a more holistic understanding of how teams function within the context of engineering design classrooms. The limitations of our research stem primarily from our methods, as no single method can answer all aspects of a research question. Instead, we tended to match our methods to the research questions at hand.

In general, our qualitative and mixed method approaches provided us with deeper understandings of phenomena in smaller samples of teams than our quantitative studies. For example, in Zajac's [3] mixed-methods study using ethnographic qualitative methods and survey data, we found that team cultural diversity impacts communication channels. The nuance described in section 3.1 would not have been possible to identify with quantitative methods. However, the nature of these mixed methods prevents us from making generalizations about the population. While quantitative analyses using inferential statistics allow for generalizations to a population of engineering students, qualitative data provide information on our specific context and should be interpreted in this context.

Our quantitative methods also provided their own strengths, but were also privy to some limitations. For example, in many cases, data collection was incredibly difficult, sometimes eliciting sample sizes that are not large enough to conduct certain types of quantitative analyses. While we have responded by altering our incentives for teams, we have also expanded into the qualitative domain, reaping the rewards that come from a deeper dive into research questions and understanding topics such as cross-cultural team diversity [3] and leader emergence [12] in ways we wouldn't have otherwise. Ultimately, the small sample sizes elicited from our quantitative studies provide limitations that are not entirely different than those faced with qualitative methods. When sample sizes are small, the generalizability of our findings is limited.

6. Conclusion

Our interdisciplinary foray into the science of student engineering design teams has elicited a number of fascinating findings, as well as avenues for future research. We certainly have a number of opportunities for future work within our university. Furthermore, this work is intended to serve as an impetus for additional cross-disciplinary work in other universities. Our team of organizational psychologists and engineering educators has engendered more fruitful research questions, a more accurate understanding of teamwork and the contexts in which it occurs, and a broader range of research approaches than we would have pursued in isolation.

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Appendix

Table 1. Overview of studies

Study	Method/Analytic Approach	Topics Considered	Resulting Findings
Zajac, 2017	Mixed methods (primarily qualitative) / ethnography; grounded theory	Team cultural diversity, technical competence, team processes (e.g., decision making [5], communication [4], problem solving [6])	*Finding 1: Team cultural diversity influences communication within teams.* *Finding 2: Diversity-based intelligence can influence the extent to which team members draw from their diverse range of expertise to make decisions.*
Lacerenza, 2017	Round robin survey design / multilevel modeling	Leader emergence, assertiveness, grit [12]	*Finding 3: Technical competence, grit, and assertiveness predict leader emergence.* *Finding 4: Perseverant team members make the most effective leaders.*
Marlow, 2018	Round robin survey design / multiple regression, multilevel modeling	Psychological safety, learning goal orientation, leader emergence [18]	*Finding 5: Team members with high learning orientation tend to emerge as leaders.* *Finding 6: Effective team leadership predicts psychological safety.*
Traylor & Croitoru, 2019	Mixed methods / grounded theory, latent profile analysis, multilevel modeling	Team conflict, gender and racial diversity, influence of teams on individual outcomes [19, 27–28]	*Finding 7: Engineering design teams characterized by profiles high in task conflict and low in relationship conflict experience higher trust, psychological safety, and team performance.* *Finding 8: Team experiences at the undergraduate level can influence individuals' career aspirations and early career decisions.* *Finding 9: Students' engineering belonging, self-efficacy, and career aspirations can improve via engineering design courses.* *Finding 10: Teams play an important role in students' experiences in engineering design courses.*

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Matthew Wettergreen, PhD is an Associate Teaching Professor at the Oshman Engineering Design Kitchen at Rice University. He teaches engineering design courses, including first-year engineering design and the follow-on engineering design courses. Additionally, he teaches students how to manufacture prototypes using low fidelity prototyping, iterative design and the use of advanced manufacturing tools. In 2017 the engineering design courses at the OEDK were combined into one of the first engineering design minors in the country, credentialing students for a course of study in engineering design, teamwork, and client-based projects. Dr. Wettergreen is the faculty mentor for Rice's Design for America chapter, for which he has been awarded the Hudspeth Award for excellence in student club mentoring. He is the designer of a number of academic products that help students improve their prototyping techniques, including a low fidelity prototyping cart and the Laser Cutter Prototyping Library.

Gary Woods received the PhD and MS in Applied Physics from Stanford University. Dr. Woods is no stranger to Rice ECE, where he earned his BA in Physics and BSEE in 1988. He has taught Senior Design to all graduating BSEE majors since 2009. His teams have won the top prize at the OEDK Design Showcase four times since then, in 2010, 2014, 2015, and 2017. In 2016 Dr. Woods won a George R. Brown Award for Superior Teaching, honoring Rice University's top teachers. The award is determined by alumni of the university. Dr. Woods is also the host of the annual "Moscars," the ELEC 305 video competition that challenges students to explain complex engineering topics through video. Dr. Woods performs research in optical probing of integrated circuits, as well as research in ultra-low-cost medical devices for developing-world neonatal wards.

Maria Oden, PhD is a Full Teaching Professor Bioengineering at Rice University, the Director of Rice University's Oshman Engineering Design Kitchen, and the Co-Director of the university's 360° Institute for Global Health. Dr. Oden has 25 years of combined academic, research, and clinical experience in biomedical engineering and engineering design. This solid background has been foundational to her leadership in biomedical engineering and use of engineering education to teach students to identify, innovate, and build devices and technologies that solve real-world problems. As director of Rice's Oshman Engineering Design Kitchen (OEDK), Oden collaborates with Rice faculty members to develop and implement engineering design and innovation curriculum programs for undergraduate students. The OEDK houses ready access to all the tools, supplies and resources students need as they work in teams to invent, test, and carry ideas and devices to their intended point of application. It is also in this innovation space that students are presented with the unique hands-on engineering design challenges brought to Oden's attention by institutes of the Texas Medical Center, industry, and local community leaders and international partners. Throughout this cumulative learning process, OEDK faculty and partners also serve as mentors who give students the expertise and guidance as they need to succeed. Oden's efforts in creating exceptional learning environments and in developing engineering design programs for undergraduates in bioengineering, the Beyond Traditional Borders (BTB) initiative and Global Health Technologies (GLHT) minor, have been recognized by the Fred Merryfield Design Award by American Society for Engineering Education (2012). The BTB program was chosen as a model program by Science magazine and awarded the Science Prize for Inquiry-Based Instruction (2012), and the Lemelson-MIT Award for Global Innovation (2013). Oden has also been selected twice for Rice's George R. Brown Prize for Superior Teaching (2012 and 2016).

Eduardo Salas, PhD is the Allyn R. & Gladys M. Cline Chair Professor and Chair of the Department of Psychology at Rice University. Previously, he was a trustee chair and Pegasus Professor of Psychology at the University of Central Florida where he also held an appointment as program director for the Human Systems Integration Research Department at the Institute for Simulation and Training (IST). Before joining IST, Eduardo was a senior research psychologist and Head of the Training Technology Development Branch of NAWC-TSD for 15 years. During this period, he served as a principal investigator for numerous R&D programs, including TADMUS, that focused on teamwork, team training, decision-making under stress and performance assessment. Eduardo has co-authored over 450 journal articles & book chapters and has co-edited 27 books. His expertise includes assisting organizations in how to foster teamwork, design and implement team training strategies, facilitate training effectiveness, manage decision making under stress, and develop performance measurement tools. He is a past president of the Society for Industrial/Organizational Psychology and the Human Factors & Ergonomics Society (HFES), fellow of the American Psychological Association (APA) and HFES, and a recipient of the Meritorious Civil Service Award from the Department of the Navy. Eduardo is also the recipient of the 2012 Society for Human Resource Management Losey Lifetime Achievement Award, the 2012 Joseph E. McGrath Award for Lifetime Achievement for his work on teams and team training and the 2016 APA Award for Outstanding Lifetime Contributions to Psychology.