Advances in Engineering Education

2023: VOLUME 11 ISSUE 3
DOI: 10.18260/3-1-1153-36046

Participation in a Team-based, First-year Engineering Design Course Associated with Improved Teaming Skills During Senior Capstone Engineering Design

ALEX NUÑEZ-THOMPSON
Oshman Engineering Design Kitchen, Rice University, Houston, TX
ACG Engineering and Construction Management, Albuquerque, New Mexico

ANN SATERBAK
Department of Biomedical Engineering, Duke University, Durham, NC

CHRISTINA RINCON
Oshman Engineering Design Kitchen, Rice University, Houston, TX
IronStride Solutions, Denver, CO

JOSH STELLING
Oshman Engineering Design Kitchen, Rice University, Houston, TX
Raytheon Intelligence & Space, Dallas, TX

GENEVERA ALLEN
Department of Electrical and Computer Engineering, Rice University, Houston, TX

MATTHEW WETTERGREEN
Oshman Engineering Design Kitchen, Department of Bioengineering,
Rice University, Houston, TX

ABSTRACT

At a small, private school in the southern US, an elective first-year design (FYD) course is offered in addition to the required capstone design course; both courses challenge student teams to tackle real-world problems. In FYD, positive team member effectiveness is cultivated through teaming instruction, demonstrations, and practice. In this study, we hypothesize whether teaming skills gained in FYD are evident in capstone design. Using a linear mixed effects model, we measure the impact of participation in FYD on teaming performance of 431 students in capstone design. Values of specific teaming skills and values of overall team member effectiveness of individuals on teams are captured using the on-line peer-evaluation tool CATME (www.catme.org). Students who participate in FYD have statistically significantly higher scores in three (of five) basic teaming skills evaluated through CATME: interacting with teammates; expecting quality; and having related knowledge, skills, and abilities. Students who participate in FYD have statistically significantly higher values for overall team member effectiveness and higher overall team member effectiveness during the first, but not the second, semester in capstone design. This longitudinal study is the first to evaluate the long-term impact of a first-year design experience regarding teaming skills, and these results add to a body of literature supporting the call for intensive early teaming experiences needed later in professional settings.

Key words: teamwork (8v), teams (14e, 14f), design projects (2b)

BACKGROUND

Motivation of Existing Study

In an increasingly competitive and globally connected world, strong teamwork skills are vital. This is especially true amongst engineers. The ABET Engineering Criteria 2000 codified teamwork as a core competency for engineering students (ABET Inc. 2019). Still, teamwork is listed as one of the most common deficiencies for engineering graduates (Radermacher and Walia 2013). For many engineering students, the most substantial teaming experience occurs at the end of their undergraduate program during senior capstone design (Beyerlein et al. 2004; Howe and Wilbarger 2006). There is a growing recognition that multiple, mentored teaming experience are necessary to prepare engineering graduates for the interconnected and team-driven world they enter after graduation.

Many engineering programs and departments have considered adding earlier teaming experiences to the curricula for their students. For example, first-year engineering courses have been created or revised to feature student teams solving design challenges or working together on short projects (Brannan and Wankat 2005; Marley and Tougaw 2019; Siniawski et al. 2016; Reid et al. 2013). In 2011, Rice University implemented a new first-year design course for its engineering students. Anecdotally, instructors in the capstone design class noted that students who participated in first-year design were more effective teammates in capstone design than their peers who did not take first-year design. We hypothesized that students who took first-year design demonstrated higher specific teaming skills and higher teammate effectiveness relative to their peers over year-long capstone design course. Thus, we investigated these claims about capstone design students with peer evaluation data from the Calibrated Assessment of Team Member Effectiveness (CATME) survey.

This section starts with a review of the literature, which describes how team effectiveness is both an observable and measurable skill through peer-feedback. The CATME survey is described in more detail, since it was implemented in both the first-year and capstone design courses at Rice University. We then provide the similarities between the first-year design and capstone courses at Rice University to contextualize our methods and results. Our results summarize how capstone design students that participated in first-year design perform differently across five teamwork metrics. Finally, we discuss how these teamwork differences change throughout the capstone design course.

Early Teamwork Training is Critical for Engineers

Teamwork is the ability to work effectively on a project or problem in cooperation with, consideration of, and collaboration within a diverse group (Hackman 2002). Passow and Passow noted that, "…technical competence is inseparably intertwined with effective collaboration" (Passow and Passow 2017). To solve problems and complete projects, teams must share a common goal, distribute workload based on expertise, and allocate time and financial resources (Hoegl and Gemuenden 2001).

Professional considerations necessitate that students graduating from engineering programs need more and diverse teaming experiences. Paul Kauffman, the executive director of the American Society for Engineering Management, recognized, "Employers may hire for technical skills, but engineers are promoted (or fired) based on their team, business, and management skills…" (National Academy of Engineering 2019). For one, knowledge and practice of teamwork skills predict contextual performance in professional settings (Morgeson, Reider, and Campion 2005). Thus, more work must be done to increase the amount and efficacy of engineering team training.

For more than 20 years, faculty have been advocating for a progressive sequence of student teaming experiences and for starting that intense teaming experiences during first-year programs (Davis and Ulseth 2013; Lewis, Aldridge, and Swamidass 1998). For example, Davis states: "For greatest success, faculty need to identify multiple places in their curricula in which project-based learning occurs and use these experiences optimally for developing students' teamwork skills." This call was bolstered with the publication of the Donia et al paper, one of the first to demonstrate transferable teamwork skills across several years (Donia, O'Neill, and Brutus 2018). Several pedagogical approaches that combine teamwork with reflective activities demonstrate that first-year engineering students gradually become more effective team members during a semester course and can make connections between effective teamwork and specific engineering design skills (Wei, Zhou, and Ohland 2021). For these reasons, opportunities for reflection on teamwork appear to have a useful place across multiple design courses in the engineering curriculum (Anwar and Menekse 2020; Hirsch and McKenna 2008).

Teamwork as an Observable and Measurable Skill

Research in the field of psychology has found that teamwork, or team effectiveness, can be improved with targeted pedagogical changes. Borrego et al. noted, "Opportunity abounds for greater connection of [industrial and organizational] (I/O) psychology teams theory and practice in facilitating engineering student teams" (Borrego et al. 2013). Other pedagogical recommendations to improve team effectiveness include team discussion around interaction rules, allowing students to self-select teams, exercises to develop mutual respect amongst team members, and grading practices that encourage team engagement (Borrego et al. 2013). In general, teamwork can be described as a social cognitive process that requires individuals to self-regulate their behavior (Bandura 1991). However, external feedback and monitoring can improve self-regulation, which could in-turn improve teamwork (Butler and Winne 1995).

Business and management literature suggests teams regularly conduct team interventions. Team interventions are brief work stoppage periods to evaluate their own performance and improve team effectiveness. Team interventions work by impacting team cognitive, affective, process, and performance outcomes (Salas et al. 2008). One McKinsey report notes that interventions should be targeted, frequent, and facilitated by organization leaders (Kruyt, Malan, and Tuffield 2011). Experts better self-monitor and, as a result, can train team members with less experience to improve project outcomes (Rentsch, Heffner, and Duffy 1994).

Salas et al. prescribes three key levers for conducting effective team interventions (Salas 2015). First, information (readings, presentations) must be provided to the individuals/teams (Salas 2015). Second, there must be a demonstration (case studies, worked problems) of the content (Salas 2015). Finally, individuals and/or teams need to practice, which includes deliberate use of the training information and expert level critique or feedback without fear of reprisal (Salas 2015). By mixing experience levels within teams and implementing targeted interventions in curricular contexts, it is possible to develop students' team skills during an undergraduate engineering program.

Peer Evaluations as a Feedback and Monitoring Tool

Peer evaluations are an impactful tool that engineering educators utilize to both monitor and provide feedback to teams. Generally, peer evaluations are distributed in the form of a survey that allows team members to rate themselves and their teammates against specific and measurable evaluation criteria established by the instructor (Gueldenzoph and May 2002; Ohland et al. 2012). Effective peer evaluations allow an instructor to pierce the veil of groupwork and learn about teamwork interactions that may be otherwise invisible (Gueldenzoph and May 2002). Ideally, peer evaluations are used both formatively and summatively (Gueldenzoph and May 2002). Adapting the best practices of peer evaluation to one system that effectively measures all the facets of team dynamics and performance is a challenge. As a result, researchers and teachers have developed personalized measures based on local and pedagogical context (Kulturel-Konak et al. 2014; Brutus and Donia 2010; Chyung et al. 2017; O'Neill et al. 2015).

Well-designed peer evaluation systems can identify the positive and negative behaviors of students that can impact project outcomes (Senkpeil et al. 2014). Negative behaviors such as free riding, missing skills, or tardiness are identified quickly using peer evaluation (Ohland et al. 2012; Senkpeil et al. 2014; Brooks and Ammons 2003). Positive behaviors are reinforced or improved (Butler and

Winne 1995; Loughry, Ohland, and Moore 2007). After distributing the peer evaluation, instructors may hold guided debriefs in order for students to actively participate in the feedback process (Brutus and Donia 2010). Instructors may also use peer evaluation as one component of a grade, which is consistent with best practices (Borrego et al. 2013; Gueldenzoph and May 2002; Mentzer et al. 2017).

CATME as an Effective Peer Evaluation Tool

One widespread, online method for team evaluation used in engineering education is the Calibrated Assessment of Team Member Effectiveness (CATME). CATME was developed at Purdue University by Matthew Ohland and other colleagues (catme.org) (Ohland et al. 2012; Loughry, Ohland, and Moore 2007; Loughry, Ohland, and Woehr 2014). This survey-based instrument uses a behaviorally anchored rating scale of 1 to 5 to evaluate students across five parsimonious metrics (Loughry, Ohland, and Moore 2007). These metrics are **C**ontributing to team's work, **I**nteracting with teammates, **K**eeping the team on track, **E**xpecting quality, and **H**aving relevant knowledge, skills, and abilities (CIKEH). Research has shown the five CIKEH metrics are the most important for measuring individual team member effectiveness (Loughry, Ohland, and Moore 2007). Each team member scores themselves and their teammates across these five metrics then receives feedback on these five metrics as well as an aggregate score relative to the team average (Ohland et al. 2012).

Since its inception, the CATME platform has been adopted by over 700 institutions across the globe (Loughry, Ohland, and Woehr 2014). Research validates its effectiveness as a peer-evaluation instrument, specifically with regards to overall accuracy (Ohland et al. 2012), depth of feedback (Wright, Milanovic, and Eppes 2018), confidential feedback system, and ease of use (Loughry, Ohland, and Woehr 2014; Hrivnak 2013). In a study of over 50,000 students across 180 institutions, interrater agreement across the five main CATME metrics was analyzed. Levels of agreement were greater than 70% for both three-person and five-person teams, suggesting that the variance for each individual metric was low (Loughry, Ohland, and Woehr 2014). Thus, CATME is a reliable and robust peer evaluation tool.

Improving Team Effectiveness Through Team Evaluations

Repeated peer evaluation can offer improvements over time in students' performance and their subsequent confidence in providing feedback to peers. It has already been stated that feedback can improve teamwork through the self-regulation theory (Butler and Winne 1995). Through several studies of repeated peer evaluations, Brutus, Donia, and others demonstrated that team performance and confidence in providing feedback to peers improves over time, irrespective of prior teamwork skills (Brutus and Donia 2010; Brutus, Donia, and Ronen 2013; Donia, O'Neill, and Brutus 2018). They note that team effectiveness improvements are independent of maturation and transfer from the university to the workplace (Brutus and Donia 2010; Brutus, Donia, and Ronen 2013).

Improvements in teaming from peer evaluation have been partially repeated in engineering education, though not to the same extent. Mentzer et al. demonstrated team effectiveness is transferrable within a freshman design thinking course (Mentzer et al. 2017). When feedback was formative, students earned higher grades (Mentzer et al. 2017). Solnosky et. al. demonstrated that with repeated team evaluation, team effectiveness was transferrable between courses (Solnosky and Fairchild 2017). Team members who had previous teaming experience were able to achieve stronger cohesiveness sooner than other teams (Solnosky and Fairchild 2017). This cohesiveness, an indicator of team unity and common group motivation, resulted in more realistic, integrated, and achievable products (Solnosky and Fairchild 2017). These findings are consistent with studies in other fields that show formative feedback allows students to develop transferrable teaming skills (Gueldenzoph and May 2002).

Because of the unique structure of the design sequence at Rice University, our research efforts were able to compare three cohorts of students during their senior year to conduct a longitudinal study, which assesses individual metrics of team performance during capstone design as a function of whether a student had taken first-year design. In the authors' exhaustive search of the engineering education literature, we found no instances where CATME, or any standard peer evaluation instrument, captured individual team effectiveness at the beginning and end of an undergraduate engineering degree program. Specifically, this study contributes to the engineering education literature by using CATME to measure the transferability of teaming skills from first-year design to capstone design.

COMPARISON OF FIRST-YEAR DESIGN AND CAPSTONE COURSES

Structure of First-Year Design and Capstone

Team-based design courses bookend the engineering curriculum at Rice University, a small, private, highly selective school in Texas, USA. In their first-year, students can take the first-year design (FYD) course, entitled Introduction to Engineering Design. The three ABET-accredited programs of Bioengineering (BIOE), Electrical Engineering (ELEC), and Mechanical Engineering (MECH) collaboratively teach a joint capstone design. The learning outcomes and course specifics remained relatively static over this study and have been described in detail elsewhere (Oden et al. 2011; Saterbak, Embree, and Oden 2012; Sack et al. 2018). Briefly, the learning outcomes for both courses are:

1. To apply the engineering design process to meet the needs of a client.
2. To work collaboratively on a team to design an engineering solution.
3. To communicate the critical steps in the design process in written, oral, and visual formats.

Table 1 summarizes similarities and differences between the FYD and capstone course structures.

Table 1. Comparison of Course Structure between FYD and Capstone Design.

Features	First-Year Design	Capstone Design
Length	One-semester	Two-semester
Course Option	Elective available to all first-year students	Required for all MECH, BIOE, and ELEC engineering students
Grading	• Written reports (technical memos) • Oral presentations • Final prototype • Teamwork • Exam	• Written reports (e.g. design foundation, design strategy, testing plan) • Oral presentations and poster • Project implementation (e.g. bill of materials, FMEA) • Intermediate and final prototypes
Faculty	Remained the same for all cohorts	Except for one year with one department, the instructors remained the same for all cohorts

Design Projects in FYD and Capstone

In both courses, teams work on client-based projects adapted from the community including the campus, local hospitals, non-profits, international partners, local industry, and other collaborators. All projects have a client, focusing the orientation of teams toward creating a solution that meets a validated unmet need. Problems are sourced by instructors and appropriately scoped into needs statements pitched to the teams at the beginning of each course. At the beginning of each course, students explore the design concept space, which includes understanding the problem, conducting research, setting design specifications, generating ideas, and selecting a proposed solution. In the design implementation space, teams are expected to iteratively build physical or digital prototypes of increasing fidelity and test them, culminating with a functional prototype that meets established design criteria. All students utilize the Oshman Engineering Design Kitchen, a 20,000 ft^2 state-of-the-art maker space fully equipped with prototyping tools and materials. Differences in the types of projects are summarized in Table 2.

Table 2. Comparison of Projects and Prototyping between FYD and Capstone Design.

Features	First-Year Design	Capstone Design
Problem complexity	Low complexity, easily decomposed	Technically challenging, complex
Project flow	• 0.5 semester: design concept space • 0.5 semester: design implementation space	• 0.5 semesters: design concept space • 1.5 semesters: design implementation space
Application of engineering principles	Participants not expected to apply engineering principles; may use a trial-and-error process	Participants are expected to apply extensive technical knowledge such as equations and models, circuit design, and knowledge of material properties
Final prototype expectations	• Partially achieve core functionality • Meet few established design specifications • Low- and some medium-fidelity prototypes	• Completely achieve core functionality • Meet most established design specifications • Medium- and some high-fidelity prototypes

Teaming Experiences and Evaluation in FYD and Capstone

FYD and capstone design represent the most intensive teaming experiences in the engineering undergraduate curriculum. In both FYD and capstone design instructors form the teams based on an internal survey (not CATME Team Maker) that each student completes about project preference, technical background, and basic demographic information. Student project preference drives the process, although a careful eye is given to minimize isolation of women and students from underrepresented minority groups (Meadows and Sekaquaptewa 2013). Both courses are multidisciplinary in nature, with students from different majors represented and often mixed within teams. Both classes use CATME as a peer evaluation tool for formative and summative assessment, in line with best practices (Wei, Zhou, and Ohland 2021; Donia, O'Neill, and Brutus 2018). Table 3 summarizes information about team composition, training, and evaluation.

Table 3. Comparison of Team Composition and Interventions between FYD and Capstone Design.

Features	First-Year Design	Capstone Design
Team size	4-5 members	4-6 members

Interventions and Support	• Lectures on teaming
	  o Team orientation (week 2)
	  o Team maintenance (week 4)
	• One or more structured team pit stops
	• Instructor and TA coaching with whole team
	• Instructor and TA coaching with individuals
		• Lectures on teaming
		  o Team fundamentals (Fall)
		  o Team maintenance (Spring)
		• Team contract
		  o Creation (Fall)
		  o Revision (Spring)
		• Instructor coaching with low performing students
		• No TAs support course

CATME peer evaluation	Three administrations	Four administrations
Impact on grade	10% of an individual's grade	Team grade calculated then adjusted to individual grade based on participation and teamwork

In FYD, specific attention is paid to team training following the best practice of instruction, demonstration, and practice (Salas 2015). Students participate in a lecture, complete in-class exercises in a low-stakes environment apart from their team, and then apply what was learned within their actual teams. There is a robust cohort of in-class TAs, who previously completed FYD. The TAs are paired up with teams to serve as mentors for the duration of the course. Instructors and TAs conduct multiple guided interventions, called "pit stops," with the teams. In addition to team interventions, TAs and instructors use CATME in a formative manner to conduct interventions with individuals.

Capstone does not emphasize team training to the same extent as FYD. Lectures on team training emphasize the creation and evaluation of a team contract, as well as conflict resolution. There are no in-class TAs in the course to serve as mentors. Instructors may conduct interventions with low-performing individuals and teams. Faculty use CATME and other inputs to adjust an individual student's grade up or down, following calculation of the team grade.

METHODS

Hypotheses

This study tested the following hypotheses:

- Hypothesis 1: In capstone, students who participated in first-year design demonstrate higher specific teaming skills.
- Hypothesis 2: In capstone, students who participated in first-year design demonstrate higher team member effectiveness than students who did not.
- Hypothesis 3: By the end of capstone, students who participated in first-year design will continue to demonstrate higher team effectiveness than the students who did not.

Data Collection and Identification of FYD Participation

Data was collected from the CATME peer evaluation instrument used in the capstone course during three academic years: 2014–2015, 2015–2016, and 2016–2017. Complete evaluations were collected from 431 students across 88 distinct teams. Many capstone teams had one or more students who had taken FYD, and roughly a quarter of capstone teams had no members who took FYD.

Student names from the capstone rosters from 2014–2017 were cross-referenced with FYD rosters from 2011-2015. Then, all 431 students in the capstone course were binned into two categories: students who participated in FYD (n=131) and students who did not participate in FYD (n=300).

Demographic data from the university registrar was available for 347 of the 431 total students in the study. Using a t-test, we compared the two groups of students for AP credit upon matriculation and GPA at graduation. We used a chi-square test to compare students across gender, race, and major. Because this was a retrospective study, no additional information about students (such as individual student participation in summer internships, research, or co-curricular clubs or activities) was available.

For all analyses, each student was assigned a unique student ID and each team was assigned a unique team ID. All students signed release forms granting access to their personal information and were notified that this data would be used in a blinded form at the start of capstone. Additionally, this study is exempt from IRB approval since the information was collected observationally for the courses.

While some courses in all engineering departments have projects, the only rigorous engineering design instruction in concert with completion of a design project through physical prototyping occurs in FYD and capstone design. Similar to other studies comparing first-year and senior-level students (Atman et al. 2005), we believe that we can detect effects of FYD from the other curricular and co-curricular components and measure its impact on capstone students.

CATME Peer-Evaluation and Performance Metrics

The five CATME skill metrics are **C**ontributing to team's work; **I**nteracting with teammates; **K**eeping the team on track; **E**xpecting quality; and **H**aving relevant knowledge, skills, and abilities – summarized as CIKEH. CIKEH measures these specific skills when working in teams on a behaviorally anchored rating scale of 1-5 with five being the best and one being the worst. A sample of the scale for the CIKEH metrics can be found in Table 4.

To measure an individual's overall team member effectiveness, we utilize the adjustment factor within the CATME instrument. The adjustment factor is calculated with CATME's proprietary algorithm, which compares an individual's average CIKEH score to their entire team's average CIKEH score (CATME.org 2020a). Within a team, the mean adjustment factor is set at 1.0 according to the internal formula. Scores above 1.0 indicate an individual is performing better relative to their teammates, and scores below 1.0 indicate an individual is performing worse relative to their teammates. The CATME

Table 4. Selected CIKEH descriptions.*

Score	Contributing to Team's Work	Interacting with Teammates	Keeping the Team on Track	Expecting Quality	Having Related Knowledge, Skills, and Abilities
5	Makes important contributions that improve the team's work.	Asks for and shows an interest in teammates' ideas and contributions.	Knows what everyone on the team should be doing and notices problems.	Cares that the team does outstanding work, even if there is no additional reward.	Acquires new knowledge or skills to improve the team's performance.
4	Demonstrates behaviors described immediately above and below.				
3	Keeps commitments and completes assignments on time.	Participates fully in team activities.	Makes sure that teammates are making appropriate progress.	Encourages the team to do good work that meets all requirements.	Demonstrates sufficient knowledge, skills, and abilities to contribute to the team's work.
2	Demonstrates behaviors described immediately above and below.				
1	Does not do a fair share of the team's work. Delivers sloppy or incomplete work.	Is defensive. Will not accept help or advice from teammates.	Is unaware of whether the team is meeting its goals.	Satisfied even if the team does not meet assigned standards.	Unable or unwilling to develop knowledge or skills to contribute to the team.

*Selections taken from scoring rubric used for CATME (CATME.org 2020b).

instrument calculates adjustment factors with and without self-ratings. Our data only analyzes the raw adjustment factor data without self-ratings. We refer to the adjustment factor as overall team member effectiveness or TME score. (Note: an individual's TME score is an "individual" metric of teaming.)

Model Development

We used R (R Core Team 2020) with lme4 (Bates et al. 2015, 4) to analyze the effect of FYD participation on the five CIKEH skill metrics and team member effectiveness with a linear mixed effects model. Linear mixed effects models are optimal for data sets of different population sizes with a hierarchical structure. Linear mixed effects models are built by testing both fixed and random effects on a dependent variable (Bates et al. 2015). The output generates slope and intercept values for each of the fixed and random effects to quantify their impact on the dependent variable. Only effects that are statistically significant are included in the model results.

Statistical significance of each effect, and thus its inclusion in the model, is determined using a forward stepwise procedure. The procedure first calculates an Akaike information criterion (AIC) for a model with a single effect. The information criterion is a numeric score of how well an effect describes the dependent variable. Then, another effect is added to the model and a new information criterion is calculated. An ANOVA test compares the two information criteria. If the information criterion value is lower and the p-value from the ANOVA test is statistically significant, the effect is kept in the model and the process is repeated. We use a Holm-Bonferroni correction to address any Type I errors generated from these progressive tests, minimizing false significance in the ANOVA test. Figures are produced with the package ggplot2 (Wickham 2016, 2).

Fixed effects measured in this study include first-year design participation (FYD) and at which of the four time points during capstone design the CATME survey was administered (Time). Random effects control for differences not measured in this study at the team- and individual-level (Team ID and Student ID, respectively).

Model 1: Analyzing the Effect of FYD Participation on CIKEH Skill Metrics

Model 1 tests whether FYD participation affects the *average individual CIKEH skill metric scores* from the entire year. Time and FYD are tested as fixed effects. Team ID and Student ID are tested as random effects. This model tested hypothesis 1.

Model 2: Analyzing the Effects of FYD Participation on Team Member Effectiveness

Model 2 tests whether FYD participation affects the *average overall team member effectiveness scores* from the entire year. Time and FYD are tested as fixed effects. Team ID and Student ID are tested as random effects. This model tested hypothesis 2.

Model 3: Analyzing the Effects of FYD Participation on Team Member Effectiveness over Time

Model 3 tests whether FYD participation affects *values of overall team member effectiveness over time*. Time and FYD are tested as interacting fixed effects. Team ID and Student ID are tested as random effects. This model tested hypothesis 3.

RESULTS

Population Statistics

Our study identified two subpopulations in the capstone course: students who did participate in first-year design (FYD) and students who did not participate in first-year design (non-FYD) (Table 5). Approximately one-third of engineering students elect to take FYD. We compared the two groups across GPA, race, gender, AP credit at time of matriculation, and major. We found that GPA, race, and gender were not significantly different ($p > 0.05$). This means that the two subpopulations were equivalent across GPA, race, and gender.

We found that AP credit at time of matriculation and major were statistically significantly different ($p < 0.05$). Students who took FYD had more AP credits upon matriculation than non-FYD students did. Given that FYD is an elective in an otherwise packed curriculum, it is not surprising that those

Table 5. Demographic data for 347 of 431 capstone students. Calculated mean values are listed with standard deviation.

	FYD Students†	Non-FYD Students‡
GPA	3.62 ± 0.32	3.55 ± 0.39
AP Credit Hours at Matriculation*	29.8 ± 16.4	24.0 ± 15.9
Gender		
Male	65.8%	67.0%
Female	34.2%	33.0%
Major*		
BIOE	29.1%	34.8%
MECH	58.1%	40.4%
ELEC	12.8%	24.8%
Race		
White	41.0%	37.0%
Asian	23.9%	21.7%
Hispanic/ Latino	21.4%	20.0%
Black or African American	2.6%	3.0%
Other§	11.1%	18.3%

† n=117
‡ n=230
* Indicates difference was statistically significant ($p < 0.05$)
§ Multiracial, Nonresident Alien, Unknown

with slightly more AP credit participated in the class. AP credits were included in a separate linear mixed effects model to test whether they improved the model's description of either the CIKEH metrics or overall team member effectiveness. In all six cases, AP credits were left out of the final model as they did not improve its description of the CIKEH metrics. Furthermore, the GPA between the two groups is not different at the senior level, suggesting that an initial difference in AP credit does not relate to differences in overall academic performance, which could affect team performance. The populations also differed with regards to major. In FYD, MECH majors were overrepresented and ELEC majors were underrepresented; in capstone the three majors were more balanced. While major distribution is different, there is no reason to expect students from one engineering major or another to be more proficient in teamwork. Thus, we felt the populations were similar enough to compare and proceeded to test the hypotheses.

Impact of FYD Participation on CIKEH Skill Metrics

Students who participated in FYD demonstrated higher specific team skills than their non-FYD peers. This result is revealed in Table 6 and was true across all five of the average CIKEH metrics for the entire year. Students scored around 4 out of 5 in all the CIKEH metrics (represented by the intercept

Table 6. Parameter estimates for Model 1, testing Hypothesis 1, for CIKEH skill metrics. Model 1 included Time as a fixed effect, which had a substantial effect in three of five skills, and FYD. Model 1 also included team- and individual-level differences, which both had a substantial effect.

	Contributing to Team's Work		Interacting with Teammates		Keeping the Team on Track		Expecting Quality		Having Related Knowledge, Skills, and Abilities	
Fixed Effects	**Estimate**	**Standard Error**	**Estimate**	**Standard Error**	**Estimate**	**Standard Error**	**Estimate**	**Standard Error**	**Estimate**	**Standard Error**
Intercept	4.02	0.04	4.1	0.0476	3.94	0.0419	4.14	0.0461	4.26	0.044
Time	-	-	-0.0313	0.0103	-	-	-0.0323	0.0103	-0.0355	0.0107
FYD	0.12	0.0644	0.122*	0.0432	0.103	0.0565	0.106*	0.0409	0.134*	0.0511
Random Effects										
Team-Level										
Intercept Variance	0.0374		0.117		0.0792		0.119		0.0646	
Individual-Level										
Intercept Variance	0.389		0.137		0.308		0.106		0.311	
Slope Variance (Time)	0.0314		0.0204		0.0256		0.0245		0.0356	

* Indicates FYD participation was statistically significant ($p < 0.05$)

row in Table 6). The FYD students scored at least 0.1 points higher than their non-FYD peers (represented by the FYD row in Table 6). Statistical significance was seen for the skills of **I**nteracting with teammates (+0.122, $p < 0.006$); **E**xpecting quality (+0.106, $p < 0.02$); and **H**aving related knowledge, skills, and abilities (+0.134, $p < 0.01$). No significance was found for **C**ontributing to team's work (+0.12, $p < 0.07$) and **K**eeping the team on track (+0.103, $p < 0.07$). This result supports hypothesis 1, which stated that students who participated in first-year design demonstrate higher specific teaming skills.

The fixed effect of Time produces a more predictive model for **I**nteracting with teammates, **E**xpecting quality, and **H**aving related knowledge, skills, and abilities (shown in the Time row of Table 6). However, time does not produce a more predictive model for **C**ontributing to team's work or **K**eeping the team on track, thus no regression estimates are given. The contributions of **C**ontribution to team's work and **K**eeping the team on track were not statistically significant. Negative Time values indicate that the scores decreased over the four time periods.

FYD participation produces detectable differences in CIKEH metric scores even with a wide range of individual scores (visualized in Figure 1). Variance between teams' CIKEH scores were low and ranged from 0.0374 to 0.119 (as seen in the Team-Level Intercept Variable row in Table 6). Individuals receive different scores for a myriad of reasons, as shown in the greater variance of individual scores (0.106 to 0.389) (as seen in the Individual-Level Intercept Variance in Table 6). Despite individual-level differences three times higher than the effect, FYD participation was associated with measurable differences between the two groups for some of the CIKEH dimensions, showing that FYD students demonstrated stronger teaming skills in capstone for the entire year.

Impact of FYD Participation On TME

Based on average TME scores from the entire year, individuals who participated in FYD were more effective team members than their non-FYD peers. The average TME score for all non-FYD individuals was 0.988 (as shown in the Intercept row in Table 7), indicating they perform below the team average. Students who participated in FYD score 0.0309 higher than their non-FYD peers ($p < 0.002$) (as shown in the FYD row in Table 7). This result supports hypothesis 2, which stated that capstone students who participated in FYD demonstrate higher values for overall team member effectiveness than students who did not.

With most TME scores ranging between 0.75 and 1.25, FYD students outperform their non-FYD peers (visualized in Figure 2). Model 2 found no significant team-level variance, which validates our model, as team averages should all be 1. Variance between individuals was 0.0083 (Individual-Level Intercept Variance in Table 7). These small differences among individual TME scores were due in part to the computational algorithm used by CATME. Still, FYD students had statistically significantly higher scores for overall team member effectiveness relative to their non-FYD peers.

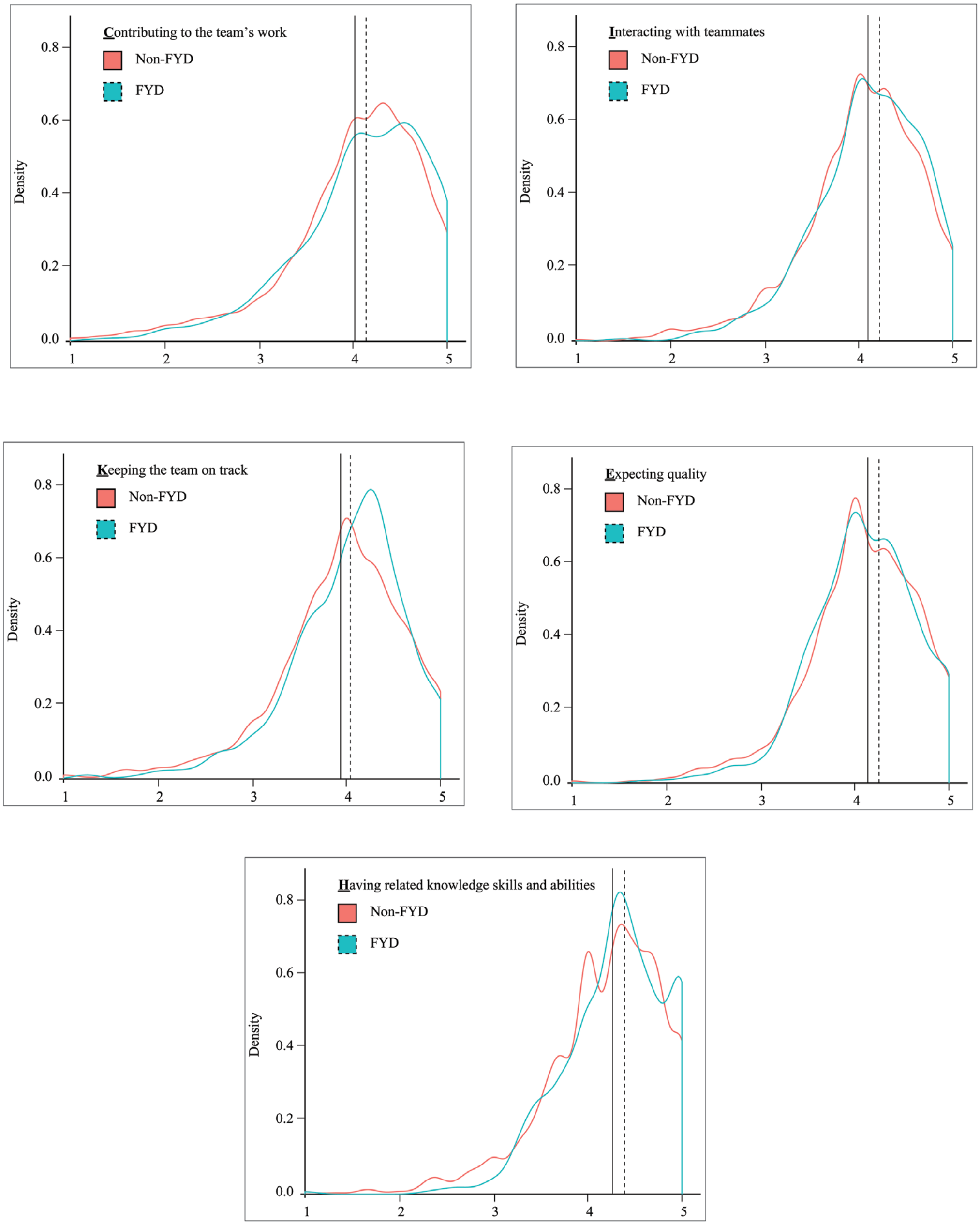

Figure 1. Density plots of individual CIKEH skill metrics overlaid with vertical lines representing model estimates for FYD and non-FYD groups.

Impact of FYD Participation on TME Over Time

At the beginning of capstone, FYD students had demonstrably higher TME scores. During the first CATME evaluation, FYD students had an average TME score of 1.025 while the non-FYD students had

Table 7. Parameter estimates for Model 2, testing Hypothesis 2, for TME. Model 2 included FYD as a fixed effect, but not time of the survey, which did not have a substantial effect. Individual-level differences were kept in Model 2, but not team-level differences, as they were not important.

	Team Member Effectiveness	
Fixed Effects	**Estimate**	**Standard Error**
Intercept	0.988	0.00531
FYD	0.0309*	0.00962
Random Effects		
Individual-Level		
Intercept Variance	0.0083	
Slope Variance (Time)	0.000971	

* Indicates FYD participation was statistically significant ($p < 0.05$)

a score of 0.987 ($p < 0.0007$) (as shown in the Time Point 1 and FYD rows in Table 8). At the second CATME evaluation, the gap between FYD and non-FYD students narrowed (1.0130 vs 0.9897, respectively), and the difference was marginally significant ($p < 0.06$). In the second semester of capstone, the TME scores of FYD students and non-FYD students were approximately the same (e.g., 0.9873 vs. 0.9945 at Time Point 4 ($p = 0.9853$)). By the end of the course, differences in TME between FYD and non-FYD students were undetectable. This result does not support hypothesis 3, which stated that by the end of capstone, students who participated in FYD will continue to demonstrate higher team effectiveness than the students who did not.

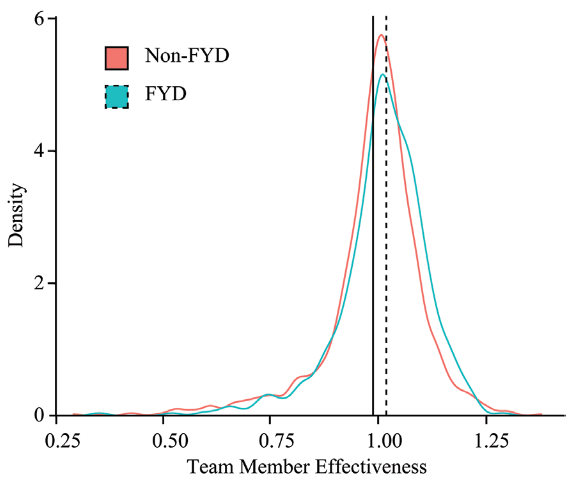

Figure 2. Density plots of TME scores overlaid with vertical lines representing model estimates for FYD and non-FYD groups.

Table 8. Parameter estimates for Model 3, testing Hypothesis 3, for TME with time interaction term. Model 3 included four sequential time points and FYD status as interacting fixed effects. Individual-level differences were important and kept in the model; no team-level differences were important and are thus excluded in the model results.

	Team Member Effectiveness	
Fixed Effects	**Estimate**	**Standard Error**
Intercept (Time Point 1)	0.987	0.00652
Time Point 2	0.00273	0.00525
Time Point 3	0.00637	0.00525
Time Point 4	0.0075	0.00525
FYD	0.038*	0.0118
Time Point 2 × FYD	-0.0117	0.00952
Time Point 3 × FYD	-0.0251	0.00952
Time Point 4 × FYD	-0.0377	0.00952
Random Effects		
Individual-Level		
Intercept Variance	0.00681	

* Indicates FYD participation was statistically significant ($p < 0.05$)

Note that the TME scores converged near 1.0 at the end of capstone (Figure 3). This is confirmed in the model results (Table 8) where TME scores of non-FYD students increased (as indicated by positive values for Time Points 2, 3, and 4) and the TME scores of FYD students decreased (as indicated by negatives interaction term values for Time Points 2, 3, 4 x FYD). Because CATME maintains a team average at 1.0 in its algorithm, if one person's score increases, another person's score must decrease. These results show that TME scores of both populations become more homogenous over time.

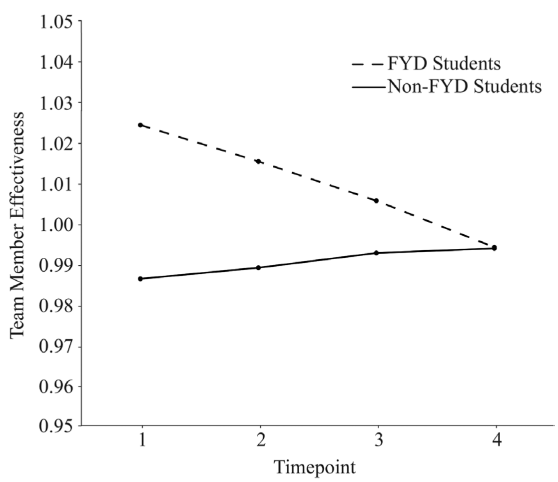

Figure 3. TME scores for FYD and non-FYD students over the two-semester capstone course.

DISCUSSION

Based on assertions from the instructors in capstone design, we were motivated to identify differences related to teamwork between the students that participated in FYD and those that did not. We showed that students who participated in FYD demonstrate detectable, specific, and stronger teaming skills in capstone design relative to their non-FYD peers; this is a unique result in the engineering education literature. We also saw that differences detected at the beginning of capstone design diminished throughout the course.

FYD Impacts Individual CIKEH Skill Metrics and TME

In capstone design, students who took FYD three years earlier showed superior teaming behavior relative to their non-FYD peers. Because CIKEH metrics directly evaluate student behaviors, we utilized them to reveal these specific differences between FYD and non-FYD students. As shown in Table 6, statistically significant increases were seen for FYD students relative to non-FYD students for the skills of **I**nteracting with teammates; **E**xpecting quality; and **H**aving related knowledge, skills, and abilities. There were no significant differences between FYD and non-FYD students in the skills of **C**ontributing to team's work and **K**eeping the team on track. While participation in FYD may not have been the sole contributor to differences among capstone students, potential relationships or associations between FYD and capstone design teamwork relative to each CIKEH metric are suggested in the following paragraphs.

The **I**nteracting with teammates metric includes communication and maintenance of interpersonal relationships (Table 4) (CATME.org 2020b). To develop **I**nteracting skills, the instructors of the FYD course use a near identical approach with team sizes, coaching, peer feedback through CATME, and grade impact (Table 3) that aligns with best practices in teaming (Salas et al. 2008; Salas 2015). Capstone students who took FYD, who have both practice and a conceptual framework of teaming, outperform non-FYD students in **I**nteracting with teammates. The structure of FYD created multiple opportunities for students to gain expertise in actively seeking other teammates' ideas and contributions and in participating fully in team activities. This result is consistent with research that reports that teams who were prepared with a conceptual framework and training outperformed the other groups (Rentsch, Heffner, and Duffy 1994; Cooke et al. 2003).

The **E**xpecting quality metric involves recognition of and motivation towards quality work (Table 4) (CATME.org 2020b). Uniquely, FYD students have an open-ended, semester-long project in an academic setting that exposes them to the complexity of design and the high level of effort needed to build a functioning device for a professional client (Table 2). While the complexity of the projects in FYD is lower to match the incoming skill-level of the students, having experience with these types of open-ended expectations and demanding client interactions in FYD could be a reason why the **E**xpecting quality behavior is stronger in capstone students who took FYD.

The **H**aving related knowledge, skills, and abilities metric measures whether students exhibit and apply these toward their capstone project (Table 4) (CATME.org 2020b). Due to their participation in the FYD course, these students have knowledge, skills, and abilities such as: the engineering design process framework and related terms, orientation for working on client-based projects, technical communication skills, and technical and prototyping skills. Prior work has shown that students with specific prototyping skills, written and oral communication skills, and research skills can transfer these to a later course or situation (Crilly and Wyman 2017; El-Abd 2016; Haas 2006). Overall, this study shows that despite an entire suite of other engineering courses, the experience in FYD may have bestowed unique knowledge, skills, and abilities that transferred and contributed positively to capstone design.

Similar **C**ontributing to team's work scores means that FYD and non-FYD members on the capstone teams were working roughly an equal amount (Table 4) (CATME.org 2020b). The absence of difference between FYD and non-FYD students is not surprising, as students in the two groups were academically similar (Table 4), and thus would be expected to make similar effort contributions toward high quality work.

The measure of **K**eeping the team on track was also not statistically significantly different between FYD and non-FYD students. **K**eeping the team on track measures how well a student monitors the team's progress and whether the student takes ownership of that progress (Table 4) (CATME.org 2020b). Without significant emphasis on project management in FYD, it is understandable and consistent with the literature (Crilly and Wyman 2017; El-Abd 2016; Foster and Spivey 2015) that there would be few differences in **K**eeping the team on track between the FYD and non-FYD groups.

Because TME is calculated from CIKEH, it is unsurprising that TME scores of FYD students were statistically significantly higher than their non-FYD peers for the entire year in capstone design (Table 7). This result is consistent with literature that states that practicing teaming skills improves future performance (Salas 2015; Rentsch, Heffner, and Duffy 1994; Cooke et al. 2003), but this is the first time it has been shown in the context of an undergraduate engineering program. Both the FYD and non-FYD cohorts have a packed curriculum of engineering classes (some with team projects), internships, and extracurricular experiences. Remarkably, despite the multitude and diversity of these considerable experiences, there are differences in overall team member effectiveness in capstone design when comparing FYD and non-FYD students. FYD students develop their teaming skills because the structure of the FYD experience is aligned to research-based practices, including thoughtful training (specifically, information, demonstration, and practice) (Salas 2015), as well as giving teams complex tasks (Borrego et al. 2013), and multiple formative feedback sessions with the opportunity to learn and improve (Borrego et al. 2013; Gueldenzoph and May 2002).

TME Scores Between FYD and Non-FYD Students Converge Over Time

Individuals become more effective team members when repeated peer evaluations are used within a course (Brutus and Donia 2010; Mentzer et al. 2017; Brutus, Donia, and Ronen 2013; Solnosky and Fairchild 2017; Donia, O'Neill, and Brutus 2018). As we have already discussed, FYD students were overall better teammates. However, by the end of capstone design, TME scores of the FYD and non-FYD groups were equivalent. As a reminder, a team's average TME score is forced to a value of 1.0 by the CATME internal algorithm. This insinuates that FYD students performed worse over time. However, we argue instead that team training, experience, and feedback within capstone was sufficient to improve the behaviors and effectiveness of non-FYD students which explains why the scores converged. As a result of CATME's algorithm, we see the convergence of the TME scores (Figure 3) as non-FYD students improve their teaming skills.

It is likely that a combination of reasons explains the convergence in TME scores, but no data directly bears on the reasons. First, repeated peer evaluation has been shown to offer improvements over time in students' performance across all experience levels (Donia, O'Neill, and Brutus 2018), so non-FYD students could be improving throughout capstone design. Additionally, by the second semester, non-FYD students now have authentic teaming experiences and may conceptualize teamwork like their FYD peers, removing the initial gap (Rentsch, Heffner, and Duffy 1994). Another plausible explanation for why the difference between FYD and non-FYD groups diminish is that the first semester of senior design approximates FYD in terms of coverage and emphasis (Table 3). Finally, it is also possible that the benefits FYD students received from their prior design experience was shared with their peers such that individuals on the teams developed strong skills as well. These embedded "experts" are able to improve the abilities of the members of their teams (Kruyt, Malan, and Tuffield 2011). Because the transferability of teaming skills is possible both within and across courses, the need for repeated exposure to team-based work in undergraduate engineering curriculum is both apparent and necessary.

Limitations and Future Research

This study makes important and novel contributions to the literature, but it is not without limitations. First, inherent to any peer evaluation system is the potential for self-reporting bias, and our study is no different. However, studies have shown that students become more effective in evaluating themselves, as well as their peers, with repeated use of peer-evaluation systems (Donia, O'Neill, and Brutus 2018; Loughry, Ohland, and Woehr 2014). Second, the study only observed student performance through the lens of whether students took the FYD course. There are other factors that could have contributed to increased TME, including changes in self-confidence (Donia, O'Neill, and Brutus 2018) or acquisition of other technical or professional skills (such as through engineering clubs, student government, other project-based learning courses, or a professional internship). A recommendation for others seeking to capture this longitudinal snapshot of student development would be to administer a survey in capstone or exit to the degree that allows students to self-report participation in these types of activities. Despite these limitations, it is still notable that significant differences were found based on FYD participation alone.

Our study produces several directions for future research exploring the mechanisms behind the measured differences between the two groups. First, one could explore the impact of pre-professional and extra-curricular activities on a student's teaming skills in this same context. Another research question regards student impressions of and receptiveness to feedback systems and how this affects the degree and nature of behavioral change, specifically in engineering design courses. As a corollary to this, each instructor who administered CATME at this school uses structured feedback to support students with low scores with the goal to help them improve. This feedback system could be modulated based on student personality or measured team dynamics. Finally, while our study analyzes the differences in teaming abilities, other future work could analyze the difference in quality of design project deliverables as a result of participating in FYD.

Implications

Teamwork is an essential professional skill for engineering practice, and engineering coursework can be an important venue for students to develop these skills. These results support the integration of more team-based projects into the undergraduate engineering curriculum, starting in the first year. Importantly, the inclusion of team-based work should be accompanied with explicit and mediated team coaching to develop transferrable teaming skills for the professional practice of engineering. We recommend following the research-based practices codified by Salas et al. to teach teaming by providing information about teamwork to the students, to demonstrate how high-performing teams behave, and to give students opportunities to practice with deliberate, expert-level feedback (Salas 2015).

If educators provide more teamwork experience with specific feedback on team performance, beyond traditional technical performance, it is possible that undergraduate students will further cultivate their teamwork capacity and abilities. Our findings support instructors adopting peer feedback systems such as CATME because they are validated and effectively measure and influence team performance over time. Widespread adoption of these practices can further equip students with the teamwork skills necessary to succeed after graduation. In summary, the results of this study advocate repeated and supported team training and practice – starting with first-year design – so that engineering students can develop teaming skills throughout their undergraduate years.

CONCLUSIONS

Students who participated in a team- and project-based one-semester first-year design course performed better as teammates in senior capstone design as measured using the CATME peer-evaluation instrument. The students that participated in FYD scored statistically significantly higher in overall team member effectiveness across the year-long capstone course, representing performance relative to their team, than their counterparts who did not take the FYD course. These same students were also statistically significantly higher in the individual metrics of **I**nteracting with teammates, **E**xpecting quality, and **H**aving relevant knowledge and skills across the year-long capstone course. We also found that over time, overall team member effectiveness becomes homogenous.

This study makes unique and important contributions to understanding individual performance in the context of student engineering teams, as there is not a body of literature in engineering education that longitudinally explores teaming skills. Our study measures how targeted team training and interventions in an FYD course were associated with improved team member effectiveness for those same students throughout senior capstone design. Based on the statistical evidence between cohorts of FYD and non-FYD students, we show that specific and important teaming skills as well as scores for overall team member effectiveness are higher in students who participated in FYD. This work validates first-year design as a foundational teaming experience, and therefore the authors advocate for well-developed, team-focused, early and ongoing design experiences for all engineering students.

ACKNOWLEDGEMENTS

Thanks to Josh Sorge for early data analysis and for coining the phrase and pronunciation of CIKEH (chick-uh) and early data collection from the CATME instrument. Andersen Chang helped us to simplify the description of the model. Tess Johnson and Dan Lee provided high level editing feedback to improve the readability of the manuscript.

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BIOSKETCH

Alex Nuñez-Thompson taught Engineering Design, Physics and AP Physics at YES Prep Public Schools in Houston, TX. Mr. Nuñez-Thompson participated as both a student and teaching assistant in the engineering design program at the Oshman Engineering Design Kitchen at Rice University. He adapted the Rice University freshman engineering design program for use in secondary education. He has a B.S. in Civil and Environmental Engineering from Rice University and currently works in Albuquerque, NM.

Ann Saterbak is Professor of the Practice in the Biomedical Department and Director of First-Year Engineering at Duke University. From 1999 to 2017, Saterbak was a faculty member in the Bioengineering Department at Rice University, where she launched many of the program's laboratory, design, and project-based courses. Saterbak has co-authored the textbooks, Bioengineering Fundamentals and Introduction to Engineering Design. Saterbak's outstanding teaching has been recognized through university-wide and regional teaching awards. In 2013, Saterbak received the ASEE Biomedical Engineering Division Theo C. Pilkington Outstanding Educator Award. For her contribution to education within biomedical engineering, she was elected Fellow in the Biomedical Engineering Society and the American Society of Engineering Education.

Christina Rincon is an ITS/Traffic Engineer at IronStride Solutions. In 2020, she received a bachelor's degree in Mechanical Engineering from Rice University. During her time at Rice, she made considerable contributions to the engineering design program at the Oshman Engineering Design Kitchen as a Design Mentor and ultimately as the Head Design Mentor, managing a team of undergraduates who support design teams. Post-graduation, she returned to the OEDK as a temporary guest lecturer to support the freshman design course during the COVID-19 pandemic.

Josh Stelling is a structural analysis engineer at Raytheon Intelligence & Space. He received a Mechanical Engineering degree with a minor in Engineering Design from Rice University in 2021. Josh had an interest in engineering design work since joining a FIRST robotics team in high school. He was an active member of Eclipse, Rice's undergraduate rocketry club that designs, manufactures, and tests experimental rocket engines and high-powered launch vehicles. Additionally, Josh worked as the Head Lab Assistant at Rice's Oshman Engineering Design Kitchen, where he helped to manage and coordinate other student Lab Assistants and assisted and educated student users of the OEDK on utilizing the tools and equipment provided to them for design work on clubs or in classes.

Genevera Allen is an Associate Professor of Electrical and Computer Engineering, Statistics and Computer Science at Rice University. She is also the Founder and Faculty Director of the Rice Center for Transforming Data to Knowledge. Dr. Allen's research focuses on developing statistical machine learning tools to help scientists make reproducible data-driven discoveries. Her work lies in the areas of interpretable machine learning, optimization, data integration, modern multivariate analysis, and graphical models with applications in neuroscience and bioinformatics. Dr. Allen is the recipient of several honors including a National Science Foundation Career award, the Engineering Research and Teaching Excellence Award at Rice University, and in 2014, she was named to the "Forbes '30 under 30': Science and Healthcare" list.

Matthew Wettergreen is the Director of the Bioengineering department's Global Medical Innovation Master's Program and an Associate Teaching Professor at the Oshman Engineering Design Kitchen at Rice University where he teaches engineering design and prototyping. Wettergreen has over ten years of experience teaching client-based engineering design courses, and a deep interest in engineering education, specifically curriculum that can be employed to build capacity for student development in makerspaces. Building off of this interest, he has taught and mentored faculty in Brazil, Malawi, and Tanzania to launch makerspaces and work with institutions to develop engineering design curriculum. 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. Wettergreen is the co-author of the textbook Introduction to Engineering Design, Springer 2021.