The Benefits of Interdisciplinary Learning Opportunities for Undergraduate Mechanical Engineering Students

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In addition, Dr. Ayala has had the opportunity to work for a number of engineering consulting companies, which have given him an important perspective and exposure to the industry. He has been directly involved in at least 20 different engineering projects related to a wide range of industries from the petroleum and natural gas industry to brewing and newspaper industries. Dr. Ayala has provided service to professional organizations such as ASME. Since 2008 he has been a member of the Committee of Spanish Translation of ASME Codes and the ASME Subcommittee on Piping and Pipelines in Spanish. Under both memberships, the following Codes have been translated: ASME B31.3, ASME B31.8S, ASME B31Q and ASME BPV Sections I.

While maintaining his industrial work active, his research activities have also been very active; Dr. Ayala has published 90 journal and peer-reviewed conference papers. His work has been presented in several international forums in Austria, the USA, Venezuela, Japan, France, Mexico, and Argentina. Dr. Ayala has an average citation per year of all his published work of 44.78.

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Abstract

Two project-based learning approaches were implemented in a 100-level information literacy class in the Mechanical Engineering program at a mid-Atlantic university. One approach, the treatment group, partnered engineering students with education students to develop and deliver engineering lessons that guide elementary school students through the engineering design process. In the second approach, the comparison group, engineering students were partnered with their engineering classmates to work on an engineering problem using the engineering design process. The two projects were designed to have similar durations and course point values. For both projects, teams were formed, and peer evaluations were completed, using the Comprehensive Assessment of Team Member Effectiveness (CATME) survey. This study examined how the two project-based learning approaches affected students' teamwork effectiveness.

Data was collected from undergraduate engineering students assigned to groups in the comparison and treatment conditions from Fall 2019 to Fall 2022. Data was collected electronically through the CATME teammate evaluations and project reflections (treatment, $n = 137$; comparison, $n = 112$). CATME uses a series of questions assessed on a 5-point Likert scale. Quantitative analysis using Analysis of Variance (ANOVA) and Covariance (ANCOVA) showed that engineering students in the treatment group expected more quality, were more satisfied, and had more task commitment than engineering students working within their discipline. However, no statistically significant differences were observed for teamwork effectiveness categories such as contribution to the team's work, interaction with teammates, keeping the team on track, and having relevant knowledge, skills, and abilities.

This result suggests that engineering students who worked in interdisciplinary teams with an authentic audience (i.e., children) perceived higher quality in their projects and had higher levels of commitment to the task than their peers in the comparison group. A thematic analysis of the written reflections was conducted to further explain the results obtained for the three categories: *expecting quality, satisfaction, and task commitment*. The thematic analysis revealed that the treatment, or interdisciplinary, groups exhibited considerably more positive reflections than their comparison peers regarding the project in all three categories, supporting results obtained quantitatively.

Introduction

The importance of interdisciplinary learning has become increasingly recognized in engineering education, especially in undergraduate engineering programs [1]. Conventional teaching methods often prioritize a narrow focus on specific disciplines, with students specializing in a specific field of study. However, with modern engineering challenges becoming more complex, it is necessary to shift towards an approach emphasizing versatility and collaboration among engineers. It has, therefore, become evident that while gaining expertise in their field of study, engineering students must also learn to collaborate with people across disciplines to navigate the complex challenges in the engineering industry effectively [2].

Integrating interdisciplinary project-based learning strategies into the engineering curriculum has emerged as a fundamental approach to fostering essential professional competencies among students [3]. Evidence indicates that these initiatives effectively develop competencies such as interdisciplinary thinking, communication, and leadership skills [4-5]. As the demand for engineers equipped with the abilities to work effectively in diverse teams continues to rise [6], the need to provide meaningful interdisciplinary collaborative learning experiences becomes paramount [7].

Research indicates that undergraduate education provides an ideal platform to help develop some of these professional competencies needed for the workforce [8]. However, conventional instructor-centered learning environments in higher education can lack essential support structures to help students develop these skills [9]. Therefore, understanding the importance and benefits of exposing undergraduate students to interdisciplinary project-based learning strategies and integrating them into their curricula can help educators provide the workforce with the expertise needed. Although various interdisciplinary project-based learning models and strategies have been highlighted in the literature [10-11], research on the benefits and the impacts of this approach on students' teamwork skills and team satisfaction is limited [12].

This paper investigates the benefits of leveraging an interdisciplinary service-learning initiative implemented in a 100-level class of a Mechanical Engineering program to enhance engineering students' teamwork effectiveness. The study builds upon the initial findings reported by Ringleb et al. [13] and Kumi et al. [14], which demonstrated that engineering students who participated in interdisciplinary projects exhibited enhanced teamwork skills and professional perseverance and received higher ratings for their knowledge, skills, and abilities. The current study aims to expand the scope of this investigation by conducting a thematic analysis of the qualitative data to identify the key themes, provide additional insights, gain a deeper understanding of the quantitative results, and investigate the factors influencing team satisfaction and team cohesiveness.

Therefore, by comparing interdisciplinary and within-disciplinary collaboration, this paper aims to determine whether and how collaborative learning affects teamwork experiences when conducted in interdisciplinary and disciplinary teams.

Methods

This mixed-methods study lasted seven semesters, from Fall 2019 to Fall 2022, at a large public university in the Mid-Atlantic region.

A total of 249 undergraduate engineering students (UES) participated in the study. Participants signed a consent form to enroll in the study. Participating students were assigned to either a comparison or treatment group based on their semester and course section (Table 1).

Semester	Implementation
Fall 2019	Treatment
Spring 2020	Treatment Comparison
Fall 2020	Comparison
Spring 2021	Treatment
Fall 2021	Comparison
Spring 2022	Treatment Comparison
Fall 2022	Comparison

Table 1. Type of implementations based on semester.

Study Context

All engineering students were enrolled in a 100-level mechanical engineering class that satisfied a general education requirement in information literacy, as well as serving as a second-semester mechanical engineering class. Both groups engaged in projects that were in progress for at least half of the semester and utilized the engineering design process in at least one component of the project.

Students in the treatment group were partnered with preservice teachers in a 300-level foundation of education class. The engineering and education classes were scheduled at the same time. This allowed the classes to meet simultaneously for an introduction to the project, to collaboratively work on their lesson plan and preliminary prototyping, and to rehearse their lesson before delivery. Additionally, teams were required to meet outside of class at least three times to organize their work, plan their lesson, and revise their lesson after the rehearsal feedback. The lesson planning process evolved over the course of this project as the investigators learned what worked best for the students and adapted to restrictions during the COVID-19 pandemic. In semesters from fall 2019 through spring 2021, students infused the engineering design process in the 5E instructional model (i.e., engage, explore, explain, elaborate, evaluate) [15]. In the spring and fall of 2022, students used the engineering design process as their sole instructional model. In all semesters, the teams collaboratively developed instructional activities to introduce engineering as a discipline and process and to support fourth or fifth grade students as they followed the engineering design process to develop a solution to a specified design challenge.

The treatment implementation was initially planned as an engineering lesson for elementary school students who would visit the campus, however this model was only realized in Fall 2019. Due to the COVID-19 pandemic, there were multiple adaptations to how the lessons were delivered: 1) in spring of 2020, the students transitioned from planning face-to-face lessons to creating virtual lessons for asynchronous delivery; 3) in spring of 2021, lessons were developed and taught online, where supplies were delivered to the elementary schools and college students picked up supplies for their projects; and 4) in spring of 2022, lessons were delivered outside on the elementary school grounds.

Participants in the comparison group worked in teams of 3-4 students. For their project, they were directed to identify a problem they could solve with basic mechanical or aerospace principles, and to follow the engineering design process to create a solution, specifically emphasizing brainstorming, prototyping, testing, and redesigning the prototype. Students worked together collaboratively in class on different aspects of the project, including evaluation of individual brainstorms, assessment of testing, and brainstorming and planning for a redesign. Due to the covid-19 pandemic, there were a few differences in the projects: 1) in spring of 2020, the students completed a prototype design before spring break. The student who possessed the prototype after campus closed continued to work on the physical model with virtual guidance from their teammates; 2) in fall of 2020 and spring of 2021, the class was taught synchronously online. Students in groups had the option of building individual prototypes if they did not or could not work together as a team outside of class; 3) in the semesters starting in the fall of 2021, students completed the project as described above with no modifications. All comparison group students were required to work outside of class time on background research, individual brainstorms, and building and testing at least two prototypes (an original and redesigned prototype). The final deliverable was an in-class group presentation.

In both conditions, the teams were provided with a set of scaffold activities to support project completion [10]. These activities included team building exercises. The treatment group completed a team charter that helped the teams to set expectations, determine roles, and discuss how team members will conduct difficult conversations if someone is not participating fully in the project. The comparison group developed ground rules and practiced difficult conversation starters for times when the ground rules were not followed. The use of scaffolding aimed at setting similar conditions for group collaboration.

Data Collection and Analysis

Data were collected using an electronic survey, including quantitative and open-ended items. Students' teamwork effectiveness was assessed using the Behaviorally Anchored Rating Scale version of the Comprehensive Assessment of Team Member Effectiveness (CATME-BARS) [16], which provides an online tool to measure a team member's performance as part of the team in five different categories: contribution to the team's work, interaction with team members, keeping the team on track, expecting quality, and having relevant knowledge, skills, and abilities [16]. CATME-BARS allows individuals to give self and peer evaluations in the five categories of teamwork. These categories comprise a number of statements to be evaluated from 1 to 5 on a Likert scale. The results from this assessment were analyzed using analysis of covariance (ANCOVA), controlling for teamwork experience, which considers participants' prior team experiences.

In addition to the CATME-BARS questions, the optional team member rating criteria questions in CATME were utilized to measure variables such as Team Satisfaction, which evaluates students' satisfaction with their current teammates [17], and Team Cohesiveness, which is targeted at understanding the team's interpersonal relationships and commitment to the task [18]. Team cohesiveness in CATME is divided into three subscales: task attraction, interpersonal cohesiveness, and task commitment. Task attraction investigates how well team members enjoy the project [18]. An example item is "Being part of the team allows team members to do enjoyable work." Interpersonal cohesiveness measures how well the students like each other [19]. An example item is "Team members get along well." Task commitment assesses how committed team members are to working together [18]. An example item is "Our team is united in trying to reach its goals for performance." Each of these variables was measured with three questions on a Likert-type scale. Results from these evaluations were collated and then analyzed using analysis of variance (ANOVA).

For the qualitative analysis, students in the treatment and comparison groups were asked to reflect on their project experiences in a written exercise at the completion of the project. These written reflection data were analyzed first deductively to identify responses aligned with the CATME variables: *expecting quality, satisfaction, and task commitment* and then inductively, to identify emergent themes within those categories [20]. Reflection responses were first coded in the various categories when they had keywords from CATME’s descriptions of those categories. All the data was coded by two researchers who negotiated agreement until consensus on all rounds of coding. Major themes from the student responses within each category were then highlighted and served as the basis for qualitative thematic analysis to complement the results obtained from the quantitative data. Themes were categorized by tone as positive or negative, and the percentage of comments for each category was calculated based on the number of comments under each theme. Finally, individual student responses within each category for both the treatment and the comparison groups were examined to understand the experiences of each group better and identify factors that may have contributed to the identified differences across these categories.

Results

Analysis of the teamwork effectiveness categories measured using CATME-BARS showed significant differences between treatment and comparison groups for *expecting quality* ($p = 0.004$) (Table 2; Fig. 1). The results indicate that students in the interdisciplinary teams scored higher than those in engineering-only teams for the *expecting quality* measure. This suggests that students in the interdisciplinary teams expressed a stronger conviction in the team's capability to produce quality work. Additionally, they expressed a greater sense that their teams fostered an environment that motivated them to pursue excellence when compared with their peers in the comparison group. However, no statistically significant differences between group means were found in *contribution to the team's work, interaction with team members, keeping the team on track, and having relevant knowledge, skills, and abilities* (Table 2; Fig. 1).

Teamwork Effectiveness Categories	Treatment			Comparison			p-value
	n	Mean	SD	n	Mean	SD	
Contribution	112	4.4354	0.51526	137	4.1704	0.69398	0.101
Interaction	112	4.3459	0.53213	137	4.2811	0.64331	0.096
Keeping the team on track	111	4.2318	0.61864	137	4.0751	0.69163	0.233
Expecting quality	112	4.3287	0.53108	118	4.0857	0.67874	0.004*
Having relevant knowledge, skills, and abilities	112	4.4354	0.51526	137	4.3101	0.67178	0.094

Table 2. Mean, Standard Deviation (SD), and *p*-values for Treatment and Comparison groups for teamwork effectiveness categories. Means and SD have been adjusted based on ANCOVA controlling for team experience. (*$p \leq 0.05$)

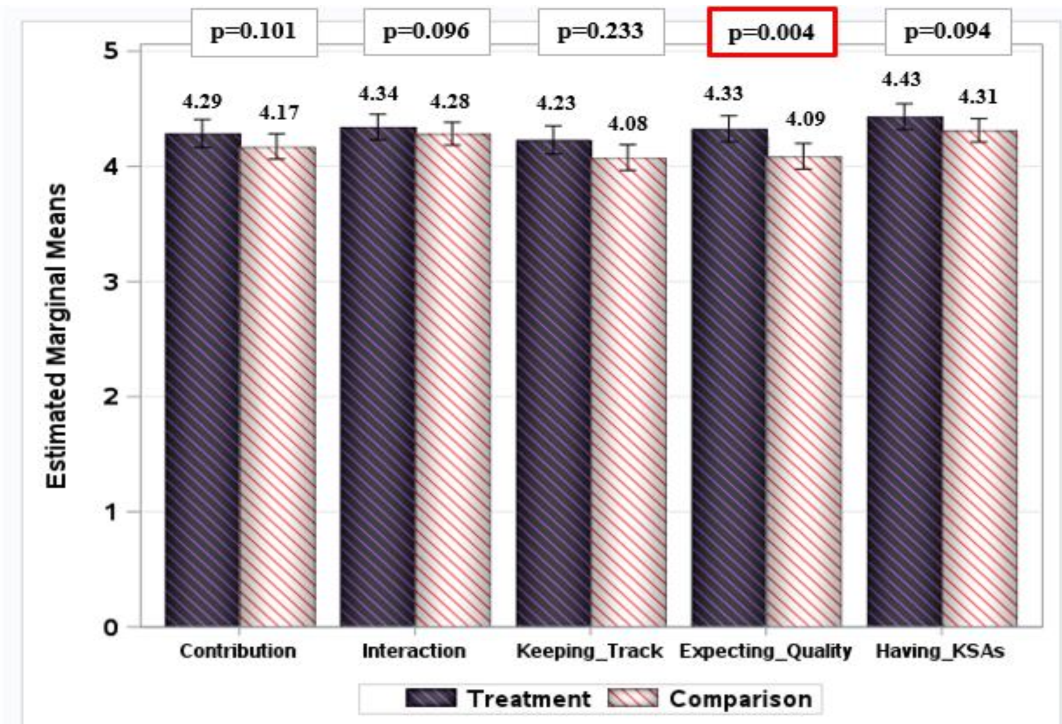

Figure 1. Adjusted Means for teamwork effectiveness variables in treatment and comparison groups. The p-values for each test are indicated in the graph.

*Significant differences in red outline

Additionally, results for *Satisfaction* also indicated greater satisfaction for the members of the treatment group than members of the comparison group (Table 3). This indicates that members of the treatment groups were more satisfied with their teammates, pleased with how they worked together, and satisfied with working in the team.

Satisfaction	Treatment			Comparison			p-value
	n	Mean	SD	n	Mean	SD	
	108	4.5124	0.70531	116	4.2845	0.99184	0.050*

Table 3. Mean, Standard Deviation (SD), and *p*-values for Treatment and Comparison groups for *Team satisfaction*. (*$p \leq 0.05$)

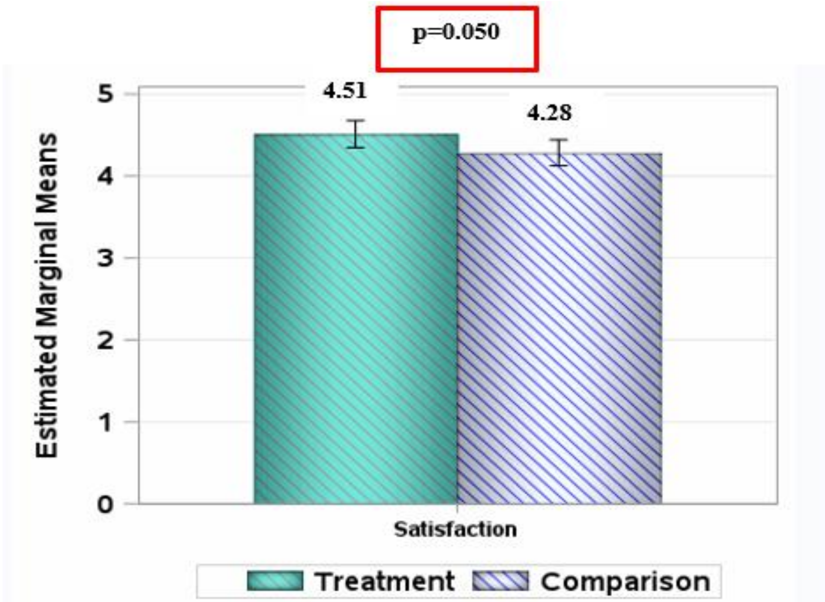

Figure 2. Estimated Means for Satisfaction in Treatment and Comparison groups. The p-values for each test are indicated in the graph.

*Significant differences in red outline

Regarding *Team Cohesiveness*, CATME data showed a significant difference between the treatment and comparison groups for *Task Commitment*. The results suggest that the treatment group may have felt more united in reaching their goals for performance and perceived greater happiness with the team's level of commitment than the comparison group members. However, there were no significant differences between the groups in *Task Attraction* and *Interpersonal Cohesiveness* (Table 4; Fig. 3).

Team Cohesiveness	n	Treatment			Comparison			p-value
		n	Mean	SD	n	Mean	SD	
Task Attraction	202	101	4.1287	0.65693	101	3.9868	0.72282	0.146
Interpersonal Cohesiveness	202	101	4.2611	0.62987	101	4.1455	0.73232	0.231
Task Commitment	202	101	3.8943	0.96562	101	3.4784	0.98613	0.003*

Table 4. Mean, Standard Deviation (SD), and *p*-values for Treatment and Comparison groups for *Team Cohesiveness*. (*$p \leq 0.05$)

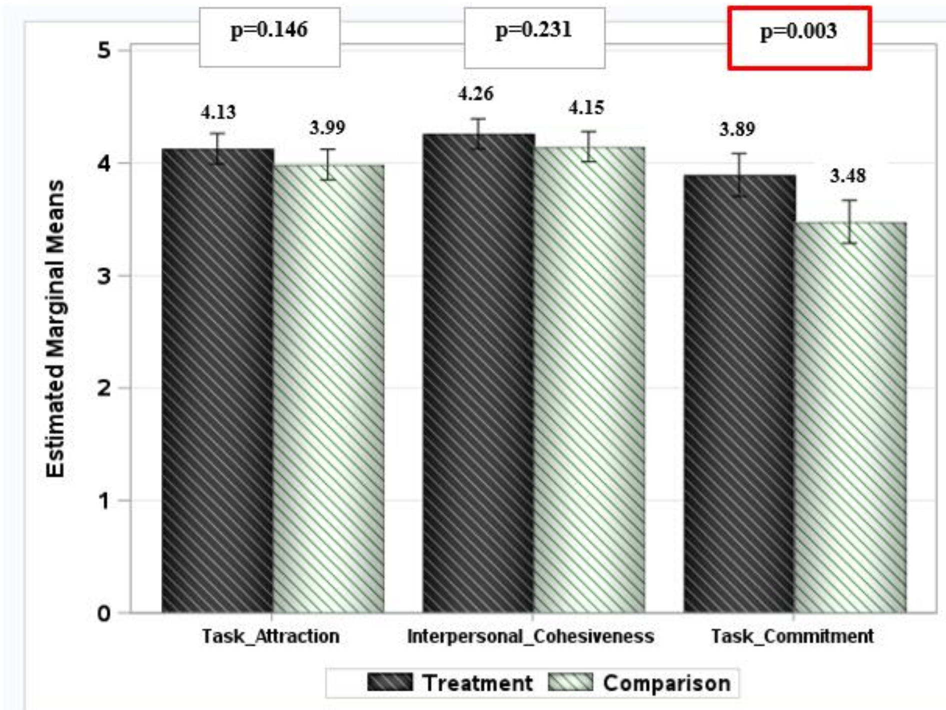

Figure 3. Estimated Means for team cohesiveness variables in Treatment and Comparison groups. The p-values for each test are indicated in the graph.

*Significant differences in red outline

The responses identified for the categories of *expecting quality, satisfaction, and task commitment* were separated into positive and negative themes. The treatment group demonstrated significantly more positive themes than the comparison group (Table 5). The identified themes suggest that the students' affective and collaborative experiences contribute to the satisfaction levels of participants in both groups. Positive team interactions, team friendships, and interaction with the children were mentioned as factors contributing to students' satisfaction.

<table>
<tr><th>Category</th><th>Tones</th><th>Themes</th><th>Treatment</th><th>Comparison</th></tr>
<tr><td rowspan="6">Satisfaction</td><td rowspan="4">Positive</td><td>Affective Outcomes
• Friendship</td><td>8.33%</td><td>13.8%</td></tr>
<tr><td>Collaborative experience
• Team Dynamics
• Team Experience</td><td>72.93%</td><td>58.6%</td></tr>
<tr><td>Other
• Kids experiences</td><td>4.17%</td><td>0.0%</td></tr>
<tr><td>Total</td><td>85.43%</td><td>72.4%</td></tr>
<tr><td rowspan="2">Negative</td><td>Collaborative experience
• Team Dynamics
• Team experience</td><td>14.57%</td><td>27.6%</td></tr>
<tr><td>Total</td><td>14.57%</td><td>27.6%</td></tr>
<tr><td rowspan="5">Expecting Quality</td><td rowspan="3">Positive</td><td>Project Outcome
• Quality work</td><td>23.3%</td><td>0.0%</td></tr>
<tr><td>Team norms
• Accountability
• Team strengths</td><td>73.4%</td><td>70.6%</td></tr>
<tr><td>Total</td><td>96.7%</td><td>70.6%</td></tr>
<tr><td rowspan="2">Negative</td><td>Team norms
• Team Dynamics</td><td>3.3%</td><td>29.4%</td></tr>
<tr><td>Total</td><td>3.3%</td><td>29.4%</td></tr>
<tr><td rowspan="4">Task Commitment</td><td rowspan="2">Positive</td><td>Team Member Commitment</td><td>94.6%</td><td>70.0%</td></tr>
<tr><td>Total</td><td>94.6%</td><td>70.0%</td></tr>
<tr><td rowspan="2">Negative</td><td>Team Member Commitment</td><td>5.4%</td><td>30.0%</td></tr>
<tr><td>Total</td><td>5.4%</td><td>30.0%</td></tr>
</table>

Table 5. Qualitative thematic analysis results showing percentages of positive and negative themes for each group per category.

In addition to the broader thematic analysis (Table 5), which focused on the extent to which positive and negative themes were identified within each category for each group, a second analysis was performed to compare the content of identified passages across the two groups. This was done to identify potential factors contributing to students' perceptions of the attitudes assessed in the CATME tool: *expecting quality, satisfaction, and task commitment*. Students in the treatment and comparison groups had both positive and negative comments related to team *satisfaction* (Table 6). Workload was discussed as a factor contributing to students' sense of satisfaction, with evenly distributed workloads associated with higher feelings of satisfaction. Project outcomes and adherence to team norms were factors seen to influence *expecting quality*. Students discussed their own and their teammates' motivation for and effort toward achieving desired grades, explaining that a unified drive to produce and submit quality work and team member accountability positively impacted their teams' ability to attain a high quality result (Table 7). Correspondingly, students also explained how negative team dynamics eroded their *expectations of quality*, with students in the comparison group reporting negative dynamics and diminished expectations more often than students in the treatment group (Table 7). In reflecting on *task commitment*, their team member commitment emerged as a predictor of their commitment and unity in accomplishing tasks (Table 8)

Satisfaction

Treatment	**Comparison**
I could not have been more satisfied with my team. From the moment we first met we all had a great dynamic and respected each other's competency. I think this mutual respect and accountability to each other created an extremely positive and comfortable work environment for all of us.	I was satisfied with my team experience overall. We all got along and became friends at the end of the day. At the very end if I had to do it again, I would like to work with the same people that I work with now.
I would say I am extremely satisfied with my team experience because that was probably my favorite part of the project. It was nice to interact with others when that has not been easy the last year.	I was satisfied with my team experience during this project. I believe that the team worked better during this project than the last, due to everyone pulling their weight and sharing the workload.
Overall, I was not satisfied with my team experience as I often felt much of the work was left to me, and my fellow team members often carried themselves in an unprofessional manner during our meetings both live and online.	I was not satisfied. my team ruined collaboration with me.

Table 6. Sample quotes from participating students in Treatment and Comparison groups on Team satisfaction.

Expecting Quality

Treatment	Co**mparison**
For submitted work, we established that it be really good quality so as to get a good grade on the assignment. We wanted everyone to try their hardest on each of their parts.	Some of the motivation I had for this project was my grade and how I need to get my diploma. Another thing that motivated me was my team and how I didn't want to let them down at all. But there was negative motivation in the fact of the workload I had this year and towards the finals week how we were adding more work on top of finishing our final project.
Our team had a great dynamic from the start. Fortunately, we all cared about the quality of our work, so no one ended up slacking off or carrying the majority of the workload. We did end up using our group chat much more as a way to communicate with each other.	I felt as though I cared more about the assignment than any other member, and that in order to get the job done I had to do the majority of it myself.
But I feel I could have put more effort into the assignment, but that would have put my own effort at "above and beyond" forcing my teammates to follow suite or suffer trying to equalize the effort.	

Table 7. Sample quotes from participating students in Treatment and Comparison groups on Expecting quality.

Task Commitment

Treatment	**Comparison**
None of us didn't participate or slack off because we knew what had to get done and we collaborated efficiently.	I felt that my team was very well versed. I benefited from my team members being very knowledgeable and helpful. During both settings my teams stepped up quick to help me if I had any questions or was struggling with any part of our assignments. They were both very fair and kind people to interact with in the class and virtually during online.
Yes! All of my teammates were not only social pleasant, but also professionally pleasant. Everyone contributed a fair amount to the project and had an overall willingness to work. At no point during this project did I feel like anyone was a burden or not carrying their weight, a pleasant surprise when working with a group.	Our team got a little more distant with each other. This really affected our productivity, but we managed to push through it.

Table 8. Sample quotes from participating students in Treatment and Comparison groups on Task Commitment.

Discussion

This study aimed to determine if and how collaborative learning experiences conducted in disciplinary vs. interdisciplinary teams affected teamwork experiences in college students. Participants of a 100-level mechanical engineering course were assigned to either a treatment or comparison group, where they collaborated and worked in either interdisciplinary or disciplinary teams. The findings suggest that students in the interdisciplinary teams displayed higher expectations of quality work from their team, reported greater satisfaction, and exhibited a stronger commitment to the task compared to their peers in the comparison group who worked solely with other engineering students in their major.

Students' affective and collaborative experiences played a critical role in determining their satisfaction levels. Members of the treatment group demonstrated higher levels of *team satisfaction*, noting greater satisfaction with their work and teammates than their colleagues in the comparison group. Both groups described the importance of affective factors in contributing to their sense of satisfaction, such as building relationships and friendships and collaborative experiences, including team dynamics and experiences. Positive team dynamics and experiences were the main determinants of satisfaction in the treatment group, while negative team dynamics, which were more frequent in the comparison group, resulted in more dissatisfaction with their teams. It should be noted, however, that while satisfaction scores were significantly higher in the treatment group, the mean scores were high (above 4.0) in both groups.

The treatment groups reported higher levels of *expecting quality*. The interdisciplinary group felt more united in reaching their goals for performance, and their team members showed greater happiness with the team's level of commitment than the comparison group members. Specifically, the qualitative analysis demonstrated that the students in the treatment group commonly expressed their desire to produce and deliver high-quality work while fostering motivation and care for their team. This included implementing accountability checks and assigning roles based on individual strengths, thus ensuring the team's ability to produce excellent work.

Additionally, the treatment group perceived a greater sense of unity in working towards their project goals than the comparison group, and thus reported higher *task commitment*. This indicates that more treatment group members found their teammates highly committed and found their team united in achieving their project goals. The participating students highlighted vital factors that contributed to positive perceptions of their teammates' *task commitment,* such as individual contributions, teammates working well together, and a strong team member commitment to achieving shared team goals. It is also possible that students in the treatment group were more committed to their project because they would be interacting with elementary students as their final deliverable and thus had an authentic audience, whereas the deliverable for the comparison group was an in-class presentation.

In addition to the positive themes, there were instances of negative team dynamics affecting the desire to produce quality work, such as a lack of interest in the project and submission of substandard work by the teammates, which resulted in lower team satisfaction. These negative themes were more pronounced in the comparison group than in the treatment group. Studies have demonstrated a positive correlation between team satisfaction and group performance [21-22]. Because the treatment group had more pressure to yield a positive performance (i.e., presenting in front of 4th graders) than the comparison group (an in-class presentation on their results), it is probable that students in the comparison group had less motivation to push for a good grade. Another possible reason for this difference is that the comparison group's project was due close to the end of the semester, while the treatment group had their field trip about three weeks before the semester ended. Finishing the project before the pressure of the end-of-semester rush may have eased the stress levels of students in the treatment groups. This was noted by a student who commented about work in other classes piling up because it was close to finals (Table 7).

Prior research has shown greater task commitment within interdisciplinary teams. An increased commitment toward team objectives was noted when an interdisciplinary team was observed over time [23]. Specifically, team members were more likely to be committed to their tasks in a collaborative environment where all members contributed equally, which occurred more frequently in the interdisciplinary teams (94.5%) than in the disciplinary teams (70%). Similarly, the results of this study indicate that interdisciplinary teams may foster greater task commitment and cohesion among students compared to those assigned to disciplinary teams.

One of the main limitations of this study is that students were not randomly assigned to either the treatment or comparison groups. Instead, students were assigned to a particular group based on their class section and class time, which could result in selection bias. Additionally, while efforts were made to ensure that both groups had similar class experiences, including the projects being worth a similar percentage of the final grade and lasting approximately the same number of weeks, expectations for students to work on the project both in and out of class, and the provision of guidelines to help students work together, the project content was different due to the nature of the final deliverable. Future research could investigate alternative methods of group assignment to improve the study. Moreover, it would be worthwhile to explore the underlying factors contributing to the variations in collaborative capabilities between disciplinary teams and interdisciplinary teams. This could provide valuable insights and help to identify strategies and interventions that can be implemented to bridge the gap and enhance collaboration across interdisciplinary teams.

Conclusion

This study shows that participation in interdisciplinary projects led to positive outcomes for undergraduate mechanical engineering students. Specifically, these students demonstrated greater care for their work and had stronger beliefs about their team's ability to produce quality work. Additionally, they reported higher satisfaction levels with their team and project and were more united in achieving their objectives. Consequently, involving students in interdisciplinary projects significantly enhanced their satisfaction, task commitment, and motivation to produce high-quality work. The interdisciplinary teams' experiences are summed up in a quote from a student, summarizing their perspectives on the project.

"I feel like it's valuable because it really gets you to work with those who you think you'd never work with. Although, working with an education student has shown me ways that an engineer like myself would have never done. I think working with such different people is good because it shows how these two different professions can work together even though they know little to nothing about each other's majors."

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References

1. Kidd, J. J., Kaipa, K., Jacks, S. J., Ringleb, S. I., Pazos, P., Gutierrez, K., ... & de Souza Almeida, L. M. (2020). What do Undergraduate Engineering Students and Preservice Teachers Learn by Collaborating and Teaching Engineering and Coding through Robotics?
2. D. M. Richter and M. C. Paretti, "Identifying barriers to and outcomes of interdisciplinarity in the engineering classroom," European Journal of Engineering Education, vol. 34, no.1, pp. 29-45, 2009.
3. MacLeod, M., & van der Veen, J. T. (2020). Scaffolding interdisciplinary project-based learning: a case study. European journal of engineering education, 45(3), 363-377.
4. Keshwani, J. & Adams, K. (2017). Cross-Disciplinary Service Learning to Enhance Engineering Identity and Improve Communication Skills. International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship, 12(1), 41-61.
5. McNair, L. D., Newswander, C., Boden, D., & Borrego, M. (2011). Student and faculty interdisciplinary identities in self-managed teams. Journal of Engineering Education, 100(2), 374-396. https://doi.org/10.1002/j.2168-9830.2011.tb00018.x
6. Ercan, M. F., & Khan, R. (2017, December). Teamwork as a fundamental skill for engineering graduates. In 2017 IEEE 6th International Conference on Teaching, Assessment, and Learning for Engineering (TALE) (pp. 24-28). IEEE.
7. Van den Beemt, A., MacLeod, M., Van der Veen, J., Van de Ven, A., van Baalen, S., Klaassen, R., & Boon, M. (2020). Interdisciplinary engineering education: A review of vision, teaching, and support. Journal of Engineering Education, 109(3), 508-555. https://doi.org/10.1002/jee.20347
8. Vogler, J. S., Thompson, P., Davis, D. W., Mayfield, B. E., Finley, P. M., & Yasseri, D. (2018). The hard work of soft skills: augmenting the project-based learning experience with interdisciplinary teamwork. Instructional Science, 46, 457-488.
9. Fisher, K., & Newton, C. (2014). Transforming the twenty-first-century campus to enhance the net-generation student learning experience: Using evidence-based design to determine what works and why in virtual/physical teaching spaces. Higher Education Research & Development, 33(5), 903-920.
10. Pazos, P., Magpili, N., Zhou, Z., & Rodriguez, L. J. (2016, June). Developing critical collaboration skills in engineering students: results from an empirical study. In 2016 ASEE Annual Conference & Exposition.
11. Pertegal-Felices, M. L., Fuster-Guilló, A., Rico-Soliveres, M. L., Azorín-López, J., & Jimeno-Morenilla, A. (2019). Practical method of improving the teamwork of engineering students using team contracts to minimize conflict situations. IEEE Access, 7, 65083-65092.
12. Lattuca, L. R., Knight, D. B., Ro, H. K., & Novoselich, B. J. (2017). Supporting the development of engineers' interdisciplinary competence. Journal of Engineering Education, 106(1), 71-97. https://doi.org/10.1002/jee.20155.
13. Ringleb, S. I., Pazos, P., Cima, F., Kumi, I. K., Ayala, O. M., Kaipa, K., ... & Lee, M. J. (2023, June). The Impact of a Multidisciplinary Service-Learning Project on Engineering Knowledge and Professional Skills in Engineering and Education Students. In *2023 ASEE Annual Conference & Exposition*.

14. Kumi, I. K., Ringleb, S. I., Ayala, O. M., Pazos, P., Cima, F., Kaipa, K., ... & Kidd, J. J. (2023). How Does Working on an Interdisciplinary Service-Learning Project vs. a Disciplinary Design Project Affect Peer Evaluators' Teamwork Skills.
15. Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). The BSCS 5E instructional model: Origins and effectiveness. *Colorado Springs, Co: BSCS*, *5*(88-98).
16. Ohland, M. W., Loughry, M. L., Woehr, D. J., Bullard, L. G., Felder, R. M., Finelli, C. J., Layton, R. A., Pomeranz, H. R., & Schmucker, D. G. (2012). The comprehensive assessment of team member effectiveness: Development of a behaviorally anchored rating scale for self-and peer evaluation. Academy of Management Learning & Education, 11(4), 609-630. doi:10.5465/amle.2010.0177
17. Van der Vegt, G. S., Emans, B. J. M., & Van de Vuert, E. (2001), "Patterns of interdependence in work teams: A two-level investigation of the relations with job and team satisfaction", Personnel Psychology, 54, 51-69
18. Carless, S. A., & De Paola, C. (2000). The measurement of cohesion in work teams. Small group research, 31(1), 71-88.
19. Loughry, M. L., & Tosi, H. L. (2008). Performance implications of peer monitoring. Organization Science, 19(6), 876-890. doi:10.1287/orsc.1080.0356
20. Fereday, J., & Muir-Cochrane, E. (2006). Demonstrating rigor using thematic analysis: A hybrid approach of inductive and deductive coding and theme development. International journal of qualitative methods, 5(1), 80-92.
21. Alshare, K., Slocombe, T., & Miller, D. (2005). The impact of team satisfaction on the performance of information-systems project team: The student perspective. In Paper presented at the Southwest Business Symposium, College of Business at the University of Central Oklahoma, Edmond, OK.
22. Zeitun, R. M., Abdulqader, K. S., & Alshare, K. A. (2013). Team satisfaction and student group performance: A cross-cultural study. Journal of Education for Business, 88(5), 286-293.
23. Pazos, P., Cima, F., Kidd, J., Ringleb, S., Ayala, O., Gutierrez, K., & Kaipa, K. (2020, June). Enhancing teamwork skills through an engineering service-learning collaboration. In 2020 ASEE Virtual Annual Conference Content Access, Virtual Online.