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The Impact of a Multidisciplinary Service-Learning Project on Engineering Knowledge and Professional Skills in Engineering and Education Students

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The impact of a multidisciplinary service-learning project on engineering knowledge and professional skills in engineering and education students

Abstract
A multidisciplinary service-learning project that involved teaching engineering to fourth and fifth graders was implemented in three sets of engineering and education classes to determine if there was an impact on engineering knowledge and teamwork skills in both the engineering and education students as well as persistence in the engineering students. Collaboration 1 paired a 100-level engineering Information Literacy class in Mechanical and Aerospace Engineering with a 300-level Educational Foundation class. Collaboration 2 combined a 300-level Electromechanical Systems class in Mechanical Engineering with a 400-level Educational Technology class. Collaboration 3 paired a 300-level Fluid Mechanics class in Mechanical Engineering Technology with a 400-level Elementary Science Methods class. Collaborations 1 and 3 interacted with fourth or fifth graders by developing and delivering lessons to the elementary students. Students in collaboration 2 worked with fifth graders in an after-school technology club. While each collaboration had its unique elements, all collaborations included the engineering design process both in classroom instruction and during the service learning project. Quantitative data were collected from both engineering and education students in a pretest/posttest design. Teamwork skills were measured in engineering students using a validated teamwork skills assessment based on peer evaluation. Each class had a comparison class taught by the same instructor that included a team project, and the same quantitative measures. Engineering students who participated in collaboration 1 were evaluated for retention, which was defined as students who were still enrolled in the college of engineering and technology two semesters after completion of the course. Engineering students also completed an evaluation of academic and professional persistence. For the engineering students, none of the assessments involving technical skills had significant differences, although the design process knowledge tests trended upward in the treatment classes. The preservice teachers in the treatment group scored significantly higher in the design process knowledge test, and preservice teachers in collaborations 1 and 3 had higher scores in the engineering knowledge test than the comparison group. Teamwork skills in the treatment group were significantly higher than in the comparison group for both engineering and education students. Thus, engineering and education students in the treatment groups saw gains in teamwork skills, while education students saw more gains in engineering knowledge. Finally, all engineering students had significantly higher professional persistence.

Introduction

Engineering education faces several challenges including, but not limited to, the need to increase the retention of students after their first year [1] and the ability to keep students engaged when they reach more difficult courses and concepts. Additionally, employers as well as the Accrediting Board for Engineering and Technology, ABET, look for disciplinary expertise and non-technical skills, including the ability to work successfully in groups, the ability to communicate both within and outside their discipline, and the ability to find information that will help them solve problems and contribute to lifelong learning.

Education majors are facing challenges given the recent incorporation of engineering practices and core ideas into the Next Generation Science Standards (NGSS) and the standards of learning in states that haven't adopted NGSS at the elementary school level. There is a need to prepare elementary teachers to confidently and competently teach engineering content [2]. Elementary preservice teachers flourish if they are exposed to and learn content that is directly relevant to the science [and engineering] standards that they will teach in their own future classrooms [3]. Thus, education courses for preservice teachers must provide the resources and opportunities to increase engineering knowledge and associated pedagogies to help address the needs of elementary teachers and their students in light of NGSS.

To help address the challenges in the education of engineers and preservice teachers, literature on collaborative learning, service learning, and peer teaching was examined. College students who participated in collaborative learning have shown improvements in long-term retention of content [4] when compared with students who attend lectures or participate in class discussions. Further, when service learning was integrated into classes, students reported increased motivation to work hard, understanding of the material, and retention of the material [5]. A study on students teaching peers provided evidence that students acting as teachers show increased breadth and depth of their own learning. Additionally, the teaching and mentoring experience helped them develop personal qualities such as confidence and perseverance, and fostered a variety of presentation and team-related skills [6]. Teaching involves breaking down ideas, building connections, and providing examples, all of which require critical thinking.

The project presented in this paper is an investigation of multidisciplinary collaborative service learning (Figure 1). In particular, engineering and education students worked together to develop and deliver engineering lessons for fourth or fifth grade students in multiple sets of engineering and education classes to improve our understanding of the impact on engineering knowledge and teamwork skills for undergraduate engineers and preservice teachers, as well as to determine if this intervention will affect the retention and persistence of engineering students. During the course of this project, the research team investigated the impact of the intervention on: 1) engineering students' understanding of engineering concepts, 2) the engineering and science knowledge in preservice teachers, 3) the collaboration skills of both engineering students and preservice teachers, 4) freshman students' academic persistence in engineering, and 5) professional persistence in engineering across different levels of engineering and education classes.

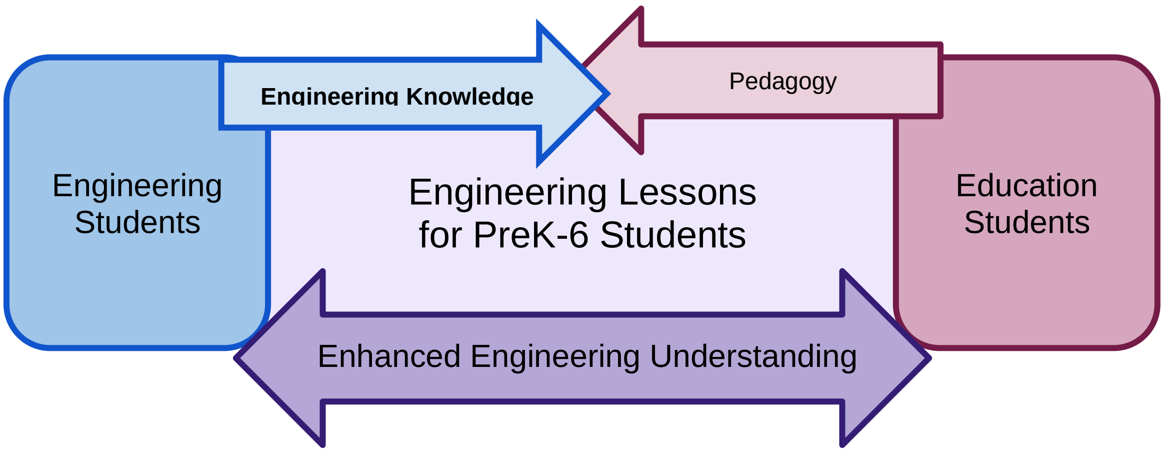


Figure 1. Multidisciplinary Collaborative Service Learning

Methods

This project was conducted across three sets of collaborating engineering and education classes from the fall of 2018 through the spring semester of 2022 (Table 1).

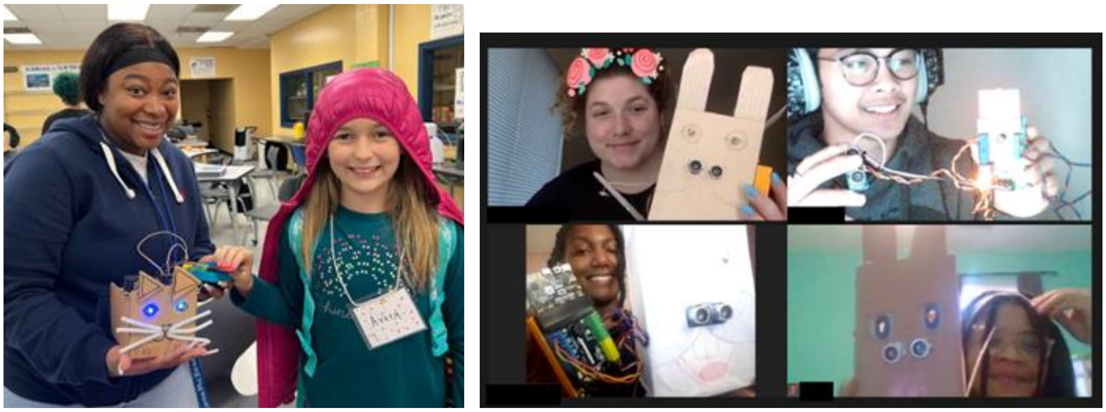
Collaborations

Collaboration 1 combined a 100-level class called Information Literacy in Mechanical and Aerospace Engineering. This class satisfied a general education requirement in information literacy as well as introductory mechanical engineering concepts including implementing the engineering design process into engineering problems. The education class was a foundations class in education. In collaboration 1, engineering and education students collaborated to develop and deliver engineering lessons to fourth or fifth graders. The original model was for the elementary students to come to campus for an engineering field trip (Figure 2a), which was adapted starting in the spring 2020 semester due to the COVID-19 pandemic to include asynchronous, online, and onsite engineering lessons (Figure 2b), based on the progression of the pandemic (Table 1)

(a) **(b)**

Figure 2. Collaboration 1 lessons during a field trip to campus (a) and at the elementary school (b)

Collaboration 2 included computational methods for the first year of the project. In year two of the project, mechanical engineering had a curriculum change, and students taking a new class, electromechanical systems, participated in this project. The preservice teachers in collaboration 2 were taking an educational technology class. Collaboration 2 met as an after-school club with fifth graders for approximately six weeks to design and build a bioinspired robot (Figure 3a). During the Covid-19 pandemic, this transitioned to zoom (Figure 3b), and returned to an in-person club in the spring of 2022 (Table 1)



(a) (b)

Figure 3. Students in collaboration 2 during the in-person after-school club (a) and working together on zoom (b).

Collaboration 3 included a fluid mechanics class in mechanical engineering technology and a science methods class in education. In this collaboration, engineering and education students visited the fourth grade classrooms to teach the students about fluid mechanics (Figure 4a), the fourth graders selected the topic they wanted their engineering lesson to be about, and the engineering and education students worked together to develop their lesson. In the original model, the fourth graders came to campus for an engineering field trip (Figure 4b), which was adapted starting in the spring 2020 semester due to the COVID-19 pandemic to include asynchronous, online, and onsite engineering lessons, based on the progression of the pandemic (Table 1).

(a) **(b)**

Figure 4. Engineering and education students teaching 4th graders about engineering in their classrooms (a) and a lesson during a field trip to campus (b)

Collab	F18	SP 19	F19	SP20	F20	SP21	F21	SP22
1	T, F2F	T, F2F C	T, F2F	T, A C	C	T, Z	C	T,OffF2F C
2	T, F2F	T, F2F	T, F2F	T, Z	C	T, Z	C	T, F2F
3	C	T, F2F	C	T, A	C	T, Z	C	T, OffF2F*

Table 1. Implementations (T = treatment, C = comparison) and treatment mode of delivery (F2F = on campus face to face implementation, A = asynchronous, Z = zoom, OffF2F = off campus face to face) *in collaboration 3, the education students were in the school and engineering students were on zoom in spring 2022

Participants

Participants were asked to sign a consent form each time they enrolled in a treatment and/or comparison class in the project (Table 2). Students who participated in more than one collaboration were noted (Table 3), and the gender (Table 4) and race/ethnicity (Table 5) of participants were collected.

	Collab 1		Collab 2		Collab 3	
Group	PSTs	UESs	PSTs	UESs	PSTs	UESs
Treatment	226	150	82	85	56	82
Comparison	222	142	51	65	92	115

Table 2. Number of consent forms signed for each collaboration. Undergraduate engineering students are UESs and preservice teachers/education students are noted as PSTs.

	Treatment		Comparison	
Number of times participated	PSTs	UESs	PSTs	UESs
1	170	237	234	245
2	98	62	79	56
3	35	5	29	5
4	3	1	3	1

Table 3. Number of students who signed consent forms for multiple collaborations. If someone participated more than 3 times, they repeated at least one class.

Gender	Treatment		Comparison	
	PST	UES	PST	UES
Male	43	201	32	225
Female	195	41	259	40
Other	5	0	4	1
No answer	63	63	50	41

Table 4. Gender distribution of all participants

Race/Ethnicity	Treatment		Comparison	
	PST	UES	PST	UES
Asian or Asian Indian	0	24	1	23
Black or African American	54	40	48	47
Hispanic, Latino or Spanish	17	10	22	25
Native American or Alaskan Native	1	2	0	0
Other	32	14	28	9
White or Caucasian	139	151	196	163
No answer	63	64	50	40

Table 5. Gender distribution of all participants

Data Collection and Analysis
Various quantitative assessments were collected to answer the research questions in this project (Table 6). To assess engineering knowledge in engineering and education students, all collaborations took the design process knowledge test (DPK), which was implemented in the fall of 2020, with major specific design process knowledge tests for engineering students [7] and education students [8]. Additionally, engineering students in collaboration 2 took a coding quiz and/or a quiz on electromechanical systems depending on the semester and course (Table 6), which were both created by the instructors. Education students in collaboration 2 also took a coding quiz created by their instructor. Engineering students participating in collaboration 3 took a test using questions from the fluid mechanics section of the fundamentals of engineering test, while education and engineering students took a science content knowledge test based on the Praxis exam. All tests were administered as a pre-test/post-test design to determine knowledge gains and analyzed using ANCOVA, controlling for pretest data.

Teamwork was initially assessed using Comprehensive Assessment of Team Member Effectiveness (CATME), an online tool that measures teamwork effectiveness skills. As preliminary data were assessed, the research team decided to add the Teamwork Skills Assessment [9].This assessment measures mission analysis, strategy formulation, situational analysis, backup behaviors, coordination, conflict management, motivating and confidence building, and affect management.

For engineering students who participated in collaboration 1, retention was measured along with academic and professional persistence, where students were considered as retained if they were still enrolled in the college of engineering and technology two semesters after completion of the class. Engineering students who participated in collaborations 2 and 3 took an academic persistence test and a professional persistence test. The academic persistence test answered the following four questions on a 7-point likert scale from strongly disagree (1) to strongly agree (7): 1) I intend to major in an engineering field, 2) I plan to remain enrolled in the college of engineering and technology over the next semester, 3) I think that earning a BS in engineering is a realistic goal for me, and 4) I am fully committed to getting my college degree in engineering. Professional persistence was measured on a 5-point likert scale, where 1 was definitely not and 5 was definitely yes, where students in collaborations 2 and 3 answered the following questions: 1) Do you see yourself pursuing a career in engineering or engineering technology? 2) How likely is it that you would do each of the following after graduation: a) work in an engineering or engineering technology job, b) work in a non-engineering/engineering technology job, c) go to graduate school in an engineering or engineering technology discipline, d) go to graduate school outside of engineering or engineering technology? Students who took the academic and professional persistence assessments were analyzed based on pre-test/post-test data. The retention data were analyzed using logistic regression with a chi-squared test and the academic and professional persistence data were analyzed using ANOVA.

Major	Spring 2019	Fall 2019	Spring 2020	Fall 2020	Spring 2021	Fall 2021	Spring 2022
Education							
Assessment of Engineering Knowledge		C1, C2	C1, C2	C1, C2, C3	C1, C2, C3	C1, C2, C3	C1, C2, C3
CATME	C1, C2, C3	C2, C3	C1, C2, C3	C3	C1, C2, C3	C3	C1, C2, C3
CS test (coding)	C2	C2	C2	C2	C2	C2	C2
DPK				C1, C2, C3	C1, C2, C3	C1, C2, C3	C1, C2, C3
Science Content	C3	C3	C3	C3	C3	C3	C3
Teamwork peer-assessment				C3	C1, C2, C3	C1, C3	C1, C2, C3
Engineering							
CATME	C1, C2, C3	C1, C2, C3	C1, C2, C3	C1, C2, C3	C1, C2, C3	C1, C2, C3	C1, C2, C3
CS test (coding)	C2	C2		C2	C2		
DPK				C1, C2	C1, C2, C3	C1, C2, C3	C1, C2, C3
Engineering Knowledge test (electric)			C2	C2	C2	C2	C2
FE test	C3	C3	C3	C3	C3	C3	C3
Persistence survey	C1, C3	C1, C3	C1, C3	C1, C2, C3	C1, C2, C3	C1, C3	C1, C3
Science Content	C3	C3	C3	C3	C3	C3	C3
Teamwork experience	C1, C3	C1, C3	C1, C3	C1, C3	C1, C2, C3	C1, C3	C1, C3
Teamwork peer-assessment				C1, C2, C3	C1, C2, C3	C1, C2, C3	C1, C2, C3

Table 6. Data collected during each semester of the project. C1, C2, and C3 stand for Collaboration 1, Collaboration 2, and Collaboration 3, respectively.

Results

Engineering Students

No differences were measured in the content knowledge tests for engineering students in collaboration 2 (CS coding test and electrical engineering knowledge test) and collaboration 3 (FE test, fluid mechanics questions and science content knowledge). The design process knowledge test showed no differences between students when all collaborations were combined, although engineering students who participated in collaboration 2 saw a marginally higher DPK score than the comparison group ($p = 0.08$). There were no differences when race and gender were included in the analysis.

CATME measured contribution, interaction, keeping the team on track, expecting quality, and having relevant knowledge skills and abilities (KSAs). Significant differences were measured between the treatment and comparison groups in expecting quality ($p = 0.02$) and having relevant KSAs ($p = 0.01$), these data are presented in more detail in a different paper [10]. Differences between race and gender were not identified. The teamwork skill assessment revealed higher teamwork skills overall for students in the treatment groups ($p = 0.02$). Prior teamwork experience did not affect the results. Additionally, across the disciplines, evaluation of teamwork skills were homogeneous. In other words, there were no significant differences in how the engineering and education students rated their peers. Education students were not more likely to rate engineering students higher or lower than engineering students rated those students. There was some concern that students from one discipline might tend to rate more critically than the other, but this pattern was not evident in the data.

Retention was defined as someone who remained in an engineering major two semesters after the completion of MAE 111 (collaboration 1). Logistic regression results showed that group (treatment or comparison) was not a predictor of retention. It was also revealed that gender and race were also not predictors of retention of students who took the MAE 111 class. When professional persistence was examined in collaboration 1, professional persistence was higher in the treatment group ($p = 0.00245$).

Results from the academic persistence survey in collaborations 2 and 3 revealed no difference between the comparison and treatment groups in terms of academic persistence after controlling for the initial score for the test in the initial survey; hence, students' intent to remain in the engineering programs was the same no matter the group they belonged to. With professional persistence, students in the treatment groups in collaborations 2 and 3 had a greater intent to pursue a career in engineering than those in the comparison group ($p = 0.035$). No differences between gender and race were found.

Education Students

Engineering knowledge was assessed across all collaborations by a version of the DPK test adapted for preservice teachers and by collaboration-specific knowledge tests. Education students participating in the treatment had significantly higher scores on the education specific DPK test ($p < 0.0001$). The engineering content knowledge was analyzed by collaboration, and a significant increase in engineering content knowledge was found for collaboration 1 ($p = 0.044$) and collaboration 3 ($p = 0.044$) only. There was no significant difference in the coding test given to education students in collaboration 2. There were no differences in race and gender in any measurements. A non-parametric analysis of the teamwork skills assessment in education students showed a significant difference between the treatment and comparison groups overall ($p = 0.0043$).

Discussion

The purpose of this project was to determine how a collaborative interdisciplinary service learning project affected engineering knowledge and teamwork skills in engineering and education students, along with retention and engineering persistence in engineering students. This project involved students in three sets of engineering and education classes, ranging from introductory to advanced content in the respective disciplines. The main findings were that in engineering students, the collaboration did not have any effect on engineering knowledge, but it did have an effect on teamwork skills and professional persistence. Education students in the treatment groups scored higher on an engineering content knowledge test and design process knowledge test than comparison groups. Additionally, their teamwork skills improved.

We hypothesized that all students would increase their engineering content knowledge, which was not true for engineering students. This may have been because the comparison groups also participated in team projects with the same engineering content. Thus, all engineering students were participating in a team project that involved learning similar content and we did not have comparison classes that were not participating in team projects. Education students did improve in engineering content knowledge and engineering design process knowledge, where their comparison groups may not have participated in a project involving as intense of an engineering project.

In this project, both engineering and education students had significantly higher teamwork skills than peers that participated in a disciplinary collaborative project without service learning. In a similar service learning project in which first year engineering students taught engineering to sixth graders, some students reported benefiting from learning how to work as a team and effectively communicate to a "real audience" [11], both skills identified as essential for engineers by both ABET accreditation outcomes and future employers. It is unclear if the increase in teamworks skills in this project was a result of the interdisciplinary collaboration in isolation or in combination with the service learning project.

A consistent concern in engineering education is retention and attrition. The results of this project showed that participating students on average exhibited more professional persistence than the comparison classes. Prior research on persistence in engineering showed that the top reasons why students left engineering in their first or second year were: 1) because engineering majors did not match the student's interests, 2) the content was difficult, and 3) too much effort was required [1]. Engaging engineering students through multidisciplinary collaborative service learning, in both the first year and in classes that are typically challenging for students, may have helped address some of these challenges by 1) providing relevance to the content, 2) incorporating active learning strategies that typically promote higher levels of engagement than traditional lecture-based instruction, and 3) showing students a tangible outcome for their learning efforts. Additionally, when first year engineering students taught engineering to sixth graders, some students reported that the experience helped them realize why they picked engineering [11]. Thus, this project may have provided the additional engagement that engineering students at all levels needed to continue to want to pursue a career in engineering. Despite the fact that professional persistence increased in students in collaboration 1 (who were primarily second semester freshman or first semester sophomores), the retention of the students was not different from the comparison teams. Future studies could investigate the impact of implementing a similar treatment to 200-level classes, instead of 300-level classes.

Conclusion

This project was successful in increasing engineering knowledge in pre-service teachers, teamwork skills in both engineering and education students, and professional persistence in engineering students. Future research could work toward understanding the cause of the differences in teamwork skills between disciplinary teams and interdisciplinary teams.

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