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Enhancing Preservice Teachers' Intention to Integrate Engineering through a Multi-Disciplinary Partnership (Evaluation)

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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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Enhancing Preservice Teachers' Intention to Integrate Engineering through a Multidisciplinary Partnership

Abstract

Though elementary educators recognize the importance of integrating engineering in their classrooms, many feel challenged and unprepared to teach engineering content. The absence of effective engineering instruction in teacher preparation programs leaves future educators unprepared for this challenge. Ed+gineering is an NSF-funded partnership between education and engineering aimed at increasing preservice teacher (PST) preparation, confidence, and intention to integrate engineering into their teaching. Ed+gineering partners education and engineering students in multidisciplinary teams within the context of their respective university courses. As part of their coursework, the teams plan and deliver culturally responsive engineering lessons to elementary school students under the guidance of one engineering and one education faculty. This paper investigates the impact of Ed+gineering on PSTs' knowledge of engineering practices, engineering pedagogical knowledge, self-efficacy to integrate engineering, and beliefs about engineering integration. The impact of Ed+gineering on participating PSTs was assessed using three collaborations involving students in engineering and education during Fall 2019 and Spring 2020. Preliminary results suggest that the Ed+gineering partnership positively impacted engineering-pedagogical knowledge, knowledge of engineering practices, and self-efficacy for integrating engineering. The specific magnitude of the impact and its implications are discussed.

Keywords: engineering instruction, K-12 education, engineering pedagogical knowledge, engineering education, preservice teachers

1. Introduction

Strong pre-college STEM education is considered fundamental to foster the necessary skills students will require to face the multiple challenges of an increasingly technological society [1]. Driven by the need to broaden participation and increase recruitment in STEM fields, policymakers have adopted many efforts to strengthen STEM inclusion in primary and secondary grade levels. The Next Generation Science Standards (NGSS) and the National Research Council's guidelines for K-12 science education exemplify the interest in promoting science and engineering content into pre-college programs in the US as a vehicle to prepare future generations to be competitive [1]. Although many schools embrace STEM education in their curricula, engineering is often the least developed domain [2], [3]. Nevertheless, engineering design-based learning has great potential for facilitating STEM integration in elementary schools [4] and stimulating students' critical skills such as problem-solving as outlined in national learning standards [5].

The benefits of engineering education in K-12 and strong support for such programs from professional and educational groups are well documented. Studies on the use of engineering design activities in primary and secondary schools' programs have shown promising benefits in students' engagement, achievement, and interest in engineering and science [6]–[10]. Moreover, providing inclusive engineering instruction in pre-college classrooms can help students understand complex scientific concepts and their applicability to real-world problems [11]. Despite the potential benefits of engineering education, the actual integration of engineering content in elementary classrooms remains a challenge. Previous evidence suggests that one reason for the relative absence of engineering in schools is teachers' lack of familiarity and confidence to teach engineering [2], [12].

Engineering's relevance as a core component of K-12 STEM education brings attention to the need to prepare future teachers to integrate engineering into their classrooms [13]. The impact of exposing elementary students to learning experiences based on engineering design activities is dependent upon teachers' understanding and effective integration of engineering concepts [14]. Thus, pre-college educator programs that prepare future teachers become natural targets for engineering integration efforts. Education programs for PSTs need to provide the resources and opportunities to increase engineering knowledge and associated pedagogies to address the need for effective engineering integration in elementary schools in light of the new science standards [2]. The integration of STEM disciplines through engineering design requires rich content and engaging practices to provide high-impact learning experiences [4]. Hence, the education community needs to rethink how to prepare future teachers with the required tools to integrate engineering at the pre-college level.

Preparing pre-college students with strong STEM backgrounds is considered essential to forming productive members of the fast-paced, changing economy [15]. Nevertheless, meeting this need is not achievable without enhancing teachers' skills and knowledge base [16]. The Ed+gineering project addresses this need by partnering education and engineering students to increase PSTs' preparation, confidence, and intention to integrate engineering into their teaching. This NSF-funded project provides PSTs with the opportunity to prepare and deliver engineering lessons to elementary students by collaborating with undergraduate engineering students (UESs). This paper describes the impact of Ed+gineering on PSTs' knowledge of engineering practices, engineering pedagogical knowledge, self-efficacy to incorporate engineering, and beliefs about engineering integration.

2. Theoretical background

Ed+gineering is a partnership between education and engineering students and faculty that aims to increase PSTs' preparation, confidence, and intention to integrate engineering into their teaching. The project uses an instructional model that relies on small group learning grounded in constructivist learning theory. This theory proposes that individuals form knowledge and meaning based on their experiences through a construction process rather than mere information transmission between them [17]. A fundamental component of constructivism is collaborative interaction, which implies that people construct their knowledge through the cognitive give and take of social interactions with other learners and mentors [18]. Constructivism also suggests that learning is affected by students' beliefs and attitudes, so they will continuously try to derive their knowledge from their mental perceptions of reality [19].

This study relied on a collaborative space for PSTs and engineering students to co-construct innovative engineering challenges for upper elementary students. The multidisciplinary Ed+gineering collaboration aims to facilitate PSTs' learning of engineering content through exposure to new and different perspectives and ideas as they interact with engineering students to share, compare, debate, and mutually build knowledge. Such interactions expect to result in positive impacts on PSTs' knowledge of engineering. Accordingly, our first hypothesis (in alternative form) is:

> *$H1_a$*. Ed+gineering has a positive influence on PSTs' knowledge of engineering practices, controlling for their initial knowledge.

The principles of constructivism have important implications for education, particularly for how teachers acquire pedagogical skills [18]. Collaboratively designing and delivering lessons promotes social learning practices, including researching and planning, peer mentoring, teaching and receiving feedback, and reflecting and revising their engineering lessons. The lesson development followed the 5E instructional model rooted in constructivism [20]. This instructional model provides the foundation for engineering design challenges that PSTs could implement into their future practice. Through collaborative engineering-based lesson preparation and delivery, PSTs can learn pedagogical methods for teaching engineering-related content in elementary school settings. These expected benefits led us to hypothesize that:

> *$H2_a$*. Ed+gineering has a positive influence on PSTs' engineering pedagogical knowledge, controlling for their initial knowledge.

Previous evidence shows that PSTs appreciated engineering's potential impact on elementary students when they taught it in collaboration with engineering students [21]. Bers and Portsmore's findings suggest that PSTs are more likely to develop positive attitudes towards engineering integration when developing engineering lessons with subject matter support from engineering students. Building from these prior findings, PSTs' exposure to engineering content using Ed+gineering's collaborative and multidisciplinary model is expected to provide them with strategies and opportunities to integrate engineering into their teaching while providing engaging and high-impact learning experiences for elementary students. Hence, the third hypothesis poses that:

> *$H3_a$*. Ed+gineering has a positive influence on PSTs' beliefs about engineering integration, controlling for their initial beliefs.

Prior research has used partnerships between PSTs and engineering students as a strategy to introduce engineering content in pre-college environments [7]. Prior studies found that collaboratively planning and teaching engineering lessons alongside engineering students enables future educators to increase their understanding of engineering and related pedagogies [7], [13], and increase PSTs' self-efficacy to teach science/engineering concepts. In the context of PSTs, we consider self-efficacy for engineering integration as a predictor of the likelihood that teachers will implement engineering lessons in their future practice. This prior research helped inform the hypothesis that:

> *$H4_a$*. Ed+gineering has a positive influence on PSTs' self-efficacy for engineering integration, controlling for their initial self-efficacy.

Continuous exposure to engineering content and relevant pedagogical practices for engineering instruction throughout PSTs' preparation programs is essential for successfully integrating engineering in their future classrooms [13]. Opportunities to teach engineering lessons collaboratively with engineering students can positively impact PSTs' knowledge and attitudes towards teaching engineering. Ed+gineering is expected to positively affect PSTs' knowledge of engineering content and pedagogies, which can help enhance their confidence and intention to integrate engineering design-based activities into their future practice.

3. Methodology

This study was conducted at a public university in the U.S. Mid-Atlantic region. Through a quasi-experimental design approach, this research assessed the impact of Ed+gineering on PSTs' engineering and pedagogical knowledge and beliefs towards engineering integration. PSTs were assigned to treatment and comparison groups based on their course section. All participating courses had two versions (treatment and comparison) with the same learning objectives and similar content. The PSTs in the treatment group completed the Ed+gineering collaboration project with engineering students as one of their class assignments. The comparison group was composed of PSTs enrolled in the same courses as the treatment group, but in sections that did not participate in the Ed+gineering cross-disciplinary collaboration with engineering students. Instead, these students completed the class using a traditional instructional approach. PSTs in the treatment group worked with engineering students in small teams of 4-6 participants to plan and deliver a culturally responsive engineering lesson to elementary school students. PSTs in the treatment group were enrolled in courses that participated in one of three collaborations with a partnering engineering class. Collaboration 1 took place in an educational foundations course, Collaboration 2 in an educational technology course, and Collaboration 3 in an elementary science methods course near the end of their academic preparation. Table 1 lists the collaborations, including the education and the partnering engineering courses. Students in all collaborations developed and delivered an engineering lesson for upper-level elementary students as part of their class activities.

Table 1. Multidisciplinary collaborations and variables

Treatment group		Response Variables
Collaboration 1 Educational Foundations + Engineering Information Literacy		Knowledge of engineering practices (KEP)
Collaboration 2 Educational Technology + Engineering Robotics/Computational Methods		Engineering pedagogical knowledge (EPK)
Collaboration 3 Elementary Science Methods + Fluid Mechanics		Beliefs about engineering integration (BEI)
		Self-efficacy for integrating engineering (SEI)

Instruments

Two survey instruments were used to assess the variables of interest. The Attitudes Survey measured PSTs' beliefs about integrating engineering into their future teaching. The instrument was adapted from existing scales [22], [23], incorporating elements of social cognitive theory [24] to measure PSTs' beliefs about engineering integration (BEI) and self-efficacy for integrating engineering (SEI). Beliefs refer to one's mental representations of reality that are accepted as truth and guide behavior [25]. Beliefs about engineering integration (10 items, $\alpha = 0.891$) assess PSTs' ideas about the benefits of integrating engineering in the classroom. A sample item is "*Implementing engineering design problems would add value to my classroom*." Self-efficacy is the strength of an individual's belief that the execution of a required behavior can be successful [24]. Self-efficacy for integrating engineering (9 items, $\alpha = 0.939$) measures the extent to which PSTs believe that they can successfully incorporate engineering-based learning into their future teaching. A sample item is "*I can explain the different aspects of the engineering design process*." All items used a 5-point Likert scale from 1 = strongly disagree to 5 = strongly agree.

A second instrument, EIPECK, measured PSTs' engineering and pedagogical knowledge. The instrument was developed based on prior work in pedagogical content knowledge [26] and previous evidence-based approaches of critical knowledge content areas for effective and culturally responsive engineering instruction [27]–[29]. The instrument assesses PSTs' self-assessed knowledge of engineering practices (KEP) and engineering pedagogical knowledge (EPK). KEP (6 items, $\alpha = 0.897$) refers to PSTs' understanding of engineering as an applied scientific discipline that can help solve real-world problems under constraints and their familiarity with engineering practices. KEP focuses on practices relevant to NGSS standards, such as defining problems clearly, evaluating different solutions considering constraints, awareness of various engineering fields, and the use of the engineering design process to develop solutions. A sample item is "*I am familiar with how the engineering design process is used by* *engineers*." EPK (8 items, $\alpha = 0.929$) refers to knowledge of pedagogical practices for teaching engineering-related content in a K-12 setting. EPK mainly focuses on the engineering design process and the strategies teachers can use to facilitate engineering instruction. An example item is "*I know how to come up with an engineering-related design problem that my students can solve in the classroom*." All items used a 5-point Likert scale from 1 = strongly disagree to 5 = strongly agree.

Participants and Method

One hundred and eighty PSTs agreed to participate in the study. They completed two separate questionnaires at two-time points. There were 180 complete responses from the EIPECK survey (comparison = 66, treatment = 114) and 158 responses from the Attitudes survey (comparison = 59, treatment = 99); thus, 22 students had missing data for the variables assessed through the Attitudes survey. The demographic information below is provided based on the larger sample of 180 students. Table 2 presents the sample's composition by gender and ethnicity grouped by collaboration. Table 3 displays the demographic information of the whole sample.

Table 2. Demographic information by collaboration

	Collaboration 1		**Collaboration 2**		**Collaboration 3**	
	Comparison (%)	**Treatment (%)**	**Comparison (%)**	**Treatment (%)**	**Comparison (%)**	**Treatment (%)**
Gender						
Male	5 (21%)	14 (19%)	-	5 (16%)	-	2 (18%)
Female	19 (79%)	56 (78%)	6 (100)%	26 (84%)	36 (100%)	9 (82%)
Other	-	2 (3%)	-	-	-	-
Ethnicity						
White	13 (54%)	43 (60%)	4 (66%)	21 (67%)	30 (83%)	7 (64%)
Hispanic	-	4 (6%)	-	3 (10%)	1 (3%)	1 (9%)
Black	6 (25%)	18 (25%)	1 (17%)	4 (13%)	2 (6%)	1 (9%)
Mixed Race	3 (13%)	4 (6%)	1 (17%)	3 (10%)	3 (8%)	1 (9%)
Other	2 (8%)	2 (3%)	-	-	-	1 (9%)
Total	**24**	**72**	**6**	**31**	**36**	**11**

Table 3. Demographic information of the whole sample

	Comparison	**Treatment**
Gender		
Male	5 (8%)	21 (18%)
Female	61 (92%)	91 (80%)
Other	-	2 (2%)
Ethnicity		
White	47 (71%)	71 (62%)
Hispanic	1 (2%)	8 (7%)
Black	9 (14%)	23 (20%)
Mixed Race	7 (11%)	8 (7%)
Other	2 (2%)	3 (3%)
Total	**66**	**114**

Data from the PSTs were collected at two time-points throughout the semester-long course. Both questionnaires were distributed within two weeks after the semester started (pre-test) and within two weeks before the end of the semester (post-test) using an online survey. Data reported in this paper include students' responses collected during Fall 2019 and Spring 2020. The data collection protocol was approved by the University's Institutional Review Board.

The impact of Ed+gineering on the four dependent variables (KEA, EPK, BEI, and SEI) was investigated using ANCOVA, with pretest scores used as control variables. Statistical analysis was conducted using IBM's SPSS version 26.

4. Results

Table 4 reports the unadjusted sample means and standard deviations of the post-test scores for treatment and comparison groups broken down by collaboration and also shown in aggregated form for the overall sample. The table reflects the sample means without controlling for pre-experimental levels of the variables. The statistical differences observed in the average adjusted scores between the comparison and treatment groups were statistically tested using Analysis of Covariance (ANCOVA), with pretest scores as control variables. The results from the ANCOVA analysis will be described in the hypothesis test section.

Table 4. Descriptive statistics

		KEApost		**EPKpost**		**BEIpost**		**SEIpost**	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Collaboration 1	Treatment	4.35	0.57	4.34	0.46	4.48	0.53	4.40	0.57
	Comparison	3.56	1.05	3.54	1.10	4.31	0.69	3.73	1.25
Collaboration 2	Treatment	4.32	0.59	4.39	0.56	4.67	0.39	4.71	0.30
	Comparison	4.17	0.59	4.25	0.86	4.66	0.30	4.69	0.30
Collaboration 3	Treatment	4.47	0.50	4.65	0.44	4.53	0.51	4.53	0.47
	Comparison	4.24	0.70	4.38	0.69	4.66	0.42	4.44	0.63
Overall	Treatment	4.35	0.56	4.38	0.49	4.52	0.51	4.46	0.53
	Comparison	3.98	0.88	4.06	0.94	4.51	0.56	4.16	0.99

Hypotheses testing

The impact of the Ed+gineering partnership on each of the variables of interest (KEP, EPK, BEI, SEI) was tested using ANCOVA controlling for the pre-test values. These analyses used the aggregate sample of all the collaborations. A dummy variable was included to indicate the collaboration number and to account for a potential effect of the collaboration.

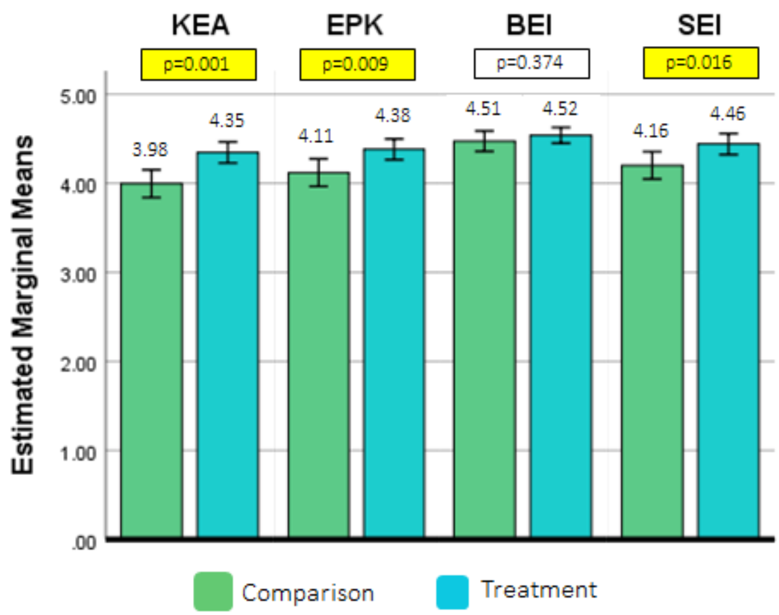
Table 5 summarizes the results of the hypothesis testing. The hypotheses predicted a positive impact of Ed+gineering on PSTs' knowledge of engineering practices (KEP), engineering pedagogical knowledge (EPK), beliefs about engineering integration (BEI), and self-efficacy for integrating engineering (SEI), after controlling for the pretest scores. The expected direction of these hypotheses (alternative form) was based on prior empirical evidence in this area. The second column in Table 5 indicates whether these hypotheses were supported. The ANCOVA analyses suggest a statistically significant effect of the intervention on three response variables: EPK, KEA, and SEI, after controlling for pre-test results. There was no evidence to support Hypothesis 4, suggesting no significant impact of Ed+gineering on BEI.

Table 5. Summary of hypothesis testing

Findings by hypothesis	**Support**
$H1_a$. The Ed+gineering project has a positive influence on PSTs knowledge of engineering practices (KEP), $F(1, 177) = 12.433$ (p-*value* < 0.01), after controlling for their incoming value (KEPpre = 3.153).	Full
$H2_a$. The Ed+gineering project has a positive influence on PSTs engineering pedagogical knowledge (EPK), $F(1, 176) = 7.073$ (p-*value* < 0.01), after controlling for their initial knowledge (EPKpre = 3.155).	Full
$H3_a$. The Ed+gineering project has a positive influence on PSTs beliefs about engineering integration (BEI), $F(1, 155) = 0.793$ (p-*value* $= 0.374$), after controlling for their initial beliefs (BEIpre = 4.287).	No
$H4_a$. The Ed+gineering project has a positive influence on PSTs self-efficacy for engineering integration (SEI), $F(1, 155) = 5.959$ (p-*value* $= 0.016$), after controlling for their initial self-efficacy (SEIpre = 3.646).	Full

Figure 1 illustrates the adjusted means for each response variable in treatment and comparison groups. The p-values for each test are indicated in the graph.

Figure 1. Error Bars for Adjusted Means



*Significant differences in yellow

Our findings revealed that the Ed+gineering project participants reported higher EPK, KEA, and SEI than students in the comparison group. The hypothesis about the influence of the Ed+gineering partnership on PSTs' BEI was not supported.

We also examined whether the effects of the intervention (Ed+gineering partnership) differed across collaborations. The interaction term involving collaboration type and type of intervention (treatment or comparison) was significant for EPK ($p\text{-}value = 0.044$), KEA ($p\text{-}value = 0.005$), and SEI ($p\text{-}value = 0.030$). Further exploration of the effects by collaboration indicated that the differences between treatment and comparison groups were greater in collaboration one than in the other two collaborations in all three variables. However, these results should be taken with caution due to the differences in sample sizes across collaborations. The authors are currently collecting additional data to conduct separate analyses for each collaboration.

Additionally, we explored if there were differential effects due to gender or ethnicity in the overall sample. Dummy variables were used to code categories of gender (0=Male, 1=Female, and 2=Other) and ethnicity (0=White or Caucasian, and 1=Non-White (other ethnicities)). The results indicate that there were no differential effects of the treatment due to gender or ethnicity. Post hoc analysis also revealed that PSTs who self-identified as White or Caucasian showed higher average values in the EPK post-test overall ($p\text{-}value < 0.05$) than their Non-White counterparts.

Limitations

The research findings have some limitations associated with the lack of randomization when assigning students to treatment and comparison groups. The use of control variables capturing the incoming levels of the response variables was implemented to address some of these limitations. Additionally, the data is based on the variables' self-assessed values, so there is a potential for bias. The authors are currently evaluating the instrument's construct validity and reliability and collecting additional objective data to address this limitation. The additional data collected includes observational and qualitative data from focus groups and individual reflections. Additional quantitative data is also being collected to increase the power of statistical analyses.

5. Discussion

This study's primary goal was to investigate the impact of Ed+gineering, a multidisciplinary collaboration on PSTs' perceived knowledge and attitudes towards engineering integration. Ed+gineering partners education and engineering students in small multidisciplinary teams to plan and deliver culturally responsive engineering lessons to upper elementary school students. Empirical evidence has previously shown that PST benefit from partnering with engineering students as a strategy to introduce engineering content in pre-college environments [7], [13], [21]. Ed+gineering employs an instructional method that relies on small group learning in which participating students co-construct innovative engineering challenges for elementary school students. We hypothesized that collaborating with engineering students would positively affect PSTs' knowledge of engineering practices, engineering pedagogical knowledge, beliefs about engineering integration, and self-efficacy for integrating engineering.

The results supported three hypotheses (H1, H2, and H3), suggesting that on average, PSTs in the Ed+gineering group perceived higher levels of knowledge of engineering practices, engineering pedagogical knowledge, and self-efficacy for integrating engineering than PSTs in the comparison group. Controlling for pretests, there was sufficient evidence that the differences in perceived knowledge and self-efficacy across treatment and comparison groups can be attributed to the intervention. Regarding PSTs' beliefs about the value of integrating engineering into classroom instruction, there were no significant differences between treatment and comparison groups. The mean values of BEI for both groups were initially relatively high (above 4.5 (strongly agree) on a 5-point Likert scale), which suggests a possible ceiling effect leaving little room for either the comparison or the treatment group to show an increase over time. Prior interventions to enhance teacher self-efficacy and beliefs suggest that attaining significant improvements is challenging [22]. In conclusion, participation in the Ed+gineering project positively impacted PSTs' knowledge and self-efficacy for engineering integration. Although these findings are encouraging, the research team is collecting additional observational and qualitative data through lesson observation, reflections, and focus groups to capture additional metrics of intention and ability to integrate engineering.

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