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Enhancing Preservice Teachers' Intention to Integrate Engineering through a Cross-Disciplinary Model

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Abstract

Although 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 cross-disciplinary model between education and engineering aimed at increasing preservice teachers' preparation, confidence, and intention to integrate engineering into their teaching. Ed+gineering partners education and engineering students in cross-disciplinary 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 preservice teachers' knowledge of engineering practices, engineering pedagogical knowledge, self-efficacy to integrate engineering, and beliefs about engineering integration. The impact of Ed+gineering on participating preservice teachers was assessed using three cross-disciplinary collaborations between students in engineering and education during fall 2019 and spring 2020. Preliminary results suggest that Ed+gineering had a positive impact on preservice teachers' 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

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Abstract

Although 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 cross-disciplinary model between education and engineering aimed at increasing preservice teachers' preparation, confidence, and intention to integrate engineering into their teaching. Ed+gineering partners education and engineering students in cross-disciplinary 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 preservice teachers' knowledge of engineering practices, engineering pedagogical knowledge, self-efficacy to integrate engineering, and beliefs about engineering integration. The impact of Ed+gineering on participating preservice teachers was assessed using three cross-disciplinary collaborations between students in engineering and education during fall 2019 and spring 2020. Preliminary results suggest that Ed+gineering had a positive impact on preservice teachers' 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

Introduction

Strong pre-college science, technology, engineering, and mathematics (STEM) education is vital for fostering the necessary skills students will require to face the multiple challenges of an increasingly technological society (National Research Council, 2012). Driven by the need to broaden participation and increase recruitment in STEM fields, policymakers have established initiatives to strengthen STEM inclusion in primary and secondary grade levels. The Next Generation Science Standards (NGSS Lead States, 2013) and the National Research Council's guidelines for K-12 science education exemplify the interest in promoting science and engineering content through pre-college programs in the USA as a vehicle to prepare future generations to be competitive (National Research Council, 2012). Although many schools embrace STEM education in their curricula, engineering is often the least developed domain (Gutierrez et al., 2020; Honey et al., 2014). Nevertheless, design-based curricular activities have great potential for facilitating STEM integration in

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elementary schools (Moore et al., 2014) and stimulating students' critical skills such as problem-solving as outlined in national learning standards (Hsu et al., 2011).

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 school programs have shown promising benefits in students' engagement, achievement, and interest in engineering and science (Carr & Strobel, 2011; Fogg-Rogers et al., 2017; Fortus et al., 2005; Katehi et al., 2009; Kolodner et al., 2003). Moreover, providing inclusive engineering instruction in pre-college classrooms can help students understand complex scientific concepts and their applicability to real-world problems (National Research Council, 2009). 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 with and confidence to teach engineering (Bybee, 2010; Gutierrez et al., 2020).

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 (Wendell, 2014). 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 (Diefes-Dux, 2014). Thus, educator programs that prepare future teachers become natural targets for engineering integration efforts. Education programs for teachers 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 (Gutierrez et al., 2020). The integration of STEM disciplines through engineering design requires rich content and engaging practices to provide high-impact learning experiences (Moore et al., 2014). 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 (Stevens & Weale, 2004). Meeting this need requires enhancing teachers' skills and knowledge base (Rubba, 1993). The Ed+gineering model addresses this need by partnering preservice teachers and engineering students to enhance preservice teachers' preparation, confidence, and intention to integrate engineering into their teaching. This NSF-funded cross-disciplinary model provides preservice teachers with the opportunity to prepare and deliver engineering lessons to elementary students by collaborating with undergraduate engineering students. This paper describes the impact of Ed+gineering on preservice teachers' knowledge of engineering practices, engineering pedagogical knowledge, self-efficacy to incorporate engineering, and beliefs about engineering integration.

Theoretical Background

Ed+gineering is a cross-disciplinary model that partners education and engineering students and faculty to increase preservice teachers' 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 (Piaget, 1985). A fundamental component of constructivism is collaborative interaction in which people construct their knowledge through the cognitive give and take of social interactions with other learners and mentors (Applefield et al., 2000). 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 (Bada & Olusegun, 2015).

This study relied on a collaborative space for preservice teachers and engineering students to co-construct innovative engineering challenges for upper elementary students with support from engineering and education faculty. The cross-disciplinary Ed+gineering model aims to facilitate preservice teachers' 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 are expected to result in positive impacts on preservice teachers' knowledge of engineering practices. Accordingly, our first hypothesis (in alternative form) is:

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

The principles of constructivism have important implications for how teachers acquire pedagogical skills (Applefield et al., 2000). Collaboratively designing and delivering lessons promotes social learning practices, including researching and planning, peer mentoring, teaching, receiving feedback, and reflecting and revising engineering lessons. The lesson development followed the 5E instructional model rooted in constructivism (Bybee et al., 2006). This instructional model provides the foundation for engineering design challenges that preservice teachers could implement into their future practice. Through collaborative engineering-based lesson preparation and delivery, preservice teachers 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 preservice teachers' engineering pedagogical knowledge, controlling for their initial knowledge.*

Previous evidence shows that preservice teachers appreciated engineering's potential impact on elementary students when they taught it in collaboration with engineering students (Bers & Portsmore, 2005). Bers and Portsmore's findings suggest that preservice teachers 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, preservice teachers' exposure to engineering content using Ed+gineering's collaborative and cross-disciplinary 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 preservice teachers' beliefs about engineering integration, controlling for their initial beliefs.*

Partnerships between preservice teachers and engineering students have been used as a strategy to introduce engineering content in pre-college environments (Fogg-Rogers et al., 2017). Some studies found that collaboratively planning and teaching engineering lessons alongside engineering students enables future educators to increase their understanding of engineering and related pedagogies (Fogg-Rogers et al., 2017; Wendell, 2014), and increase preservice teachers' self-efficacy to teach science/engineering concepts. In the context of preservice teachers, 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 preservice teachers' self-efficacy for engineering integration, controlling for their initial self-efficacy.*

Continuous exposure to engineering content and relevant pedagogical practices for engineering instruction throughout preservice teachers' preparation programs is essential for successfully integrating engineering in their future classrooms (Wendell, 2014). Opportunities to teach engineering lessons collaboratively with engineering students can positively impact preservice teachers' knowledge and attitudes towards teaching engineering. Ed+gineering is expected to positively affect preservice teachers' knowledge of engineering practices and pedagogies, which can help enhance their confidence and intention to integrate engineering design-based activities into their future practice. Figure 1 displays the statistical model including the variables and relationships explored in the form of research hypotheses.

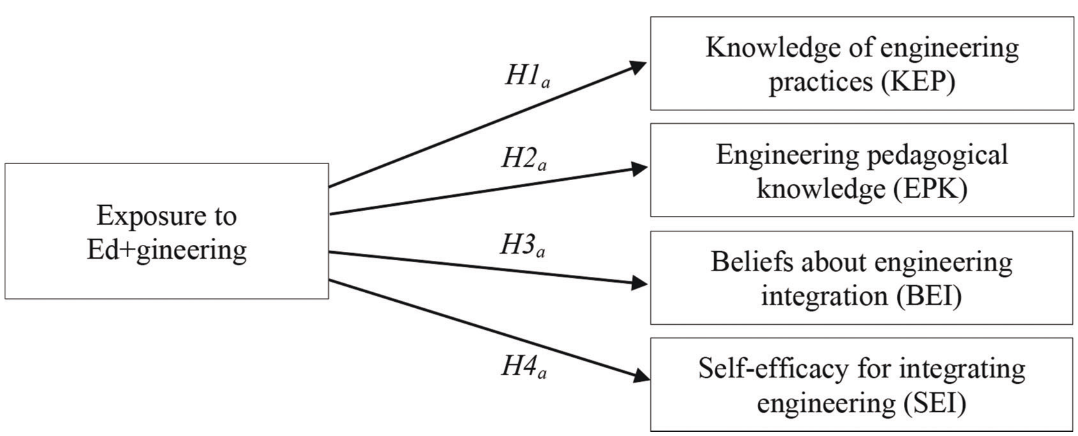

Figure 1. Statistical model: variables and research hypotheses. *Note.* Exposure to Ed+gineering indicates whether participants were exposed to treatment or comparison.

Table 1
Cross-disciplinary collaborations.

	Education course	Engineering course
Collaboration 1	Educational foundations	Engineering information literacy
Collaboration 2	Educational technology	Engineering robotics
Collaboration 3	Elementary science methods	Fluid mechanics

Methodology

This study was conducted at a large public university in the U.S. Mid-Atlantic region. This research used a quasi-experimental approach to assess the impact of Ed+gineering on preservice teachers' engineering and pedagogical knowledge and beliefs towards engineering integration. Preservice teachers 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 preservice teachers 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 preservice teachers enrolled in the same courses as the treatment, 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. Preservice teachers 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. They 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 partnering engineering and education courses participating in the collaborations. Students in all collaborations developed and delivered an engineering lesson for upper-level elementary students as part of their class activities.

Instruments

Two survey instruments assessed the variables of interest. The Attitudes Survey measured preservice teachers' beliefs about integrating engineering into their future teaching. The instrument was adapted from existing scales (Rich et al., 2017; Yaşar et al., 2006), incorporating elements of social cognitive theory (Bandura, 1989a) to measure preservice teachers' 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 (Sigel, 1985). BEI (10 items, $\alpha = 0.891$) assess preservice teachers' 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 (Bandura, 1989a). SEI (9 items, $\alpha = 0.939$) measures the extent to which preservice teachers 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 preservice teachers' perceived engineering and pedagogical knowledge. The instrument builds on prior work in pedagogical content knowledge (Shulman, 1986) and previous evidence-based approaches of critical knowledge content areas for effective and culturally responsive engineering instruction (Cunningham & Carlsen, 2014; Hsiao, 2015; Richards et al., 2007). It measures preservice teachers' self-assessed knowledge of engineering practices (KEP) and engineering pedagogical knowledge (EPK). KEP (6 items, $\alpha = 0.897$) refers to preservice teachers' 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 the Next Generation Science 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 preservice teachers agreed to participate in the study. They completed two questionnaires during the academic period. 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 and the whole sample.

Data from the preservice teachers were collected using two questionnaires at two points during the semester. A pre-test was deployed during the first two weeks of the semester and the post-test took place within two weeks before the end of the semester 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 pre-test scores used as control variables. Statistical analysis was conducted using IBM's SPSS version 26.

Results

Table 3 reports the unadjusted sample means and standard deviations of the post-test scores for treatment and comparison groups broken down by collaboration and in aggregated form for the overall sample. The table reflects the sample means based on the raw data post-intervention without controlling for pre-experimental levels of the variables. The results from the ANCOVA will be described in the hypothesis test section.

Table 2
Demographic information by collaboration and total sample.

	Collaboration 1		**Collaboration 2**		**Collaboration 3**		**Total sample**	
	C (%)	**T (%)**	**C (%)**	**T (%)**	**C (%)**	**T (%)**	**C (%)**	**T (%)**
Gender								
Male	5 (*21%*)	14 (*19%*)	—	5 (*16%*)	—	2 (*18%*)	5 (*8%*)	21 (*18%*)
Female	19 (*79%*)	56 (*78%*)	6 (*100*)%	26 (*84%*)	36 (*100%*)	9 (*82%*)	61 (*92%*)	91 (*80%*)
Other	—	2 (*3%*)	—	—	—	—	—	2 (*2%*)
Ethnicity								
White	13 (*54%*)	43 (*60%*)	4 (*66%*)	21 (*67%*)	30 (*83%*)	7 (*64%*)	47 (*71%*)	71 (*62%*)
Hispanic	—	4 (*6%*)	—	3 (*10%*)	1 (*3%*)	1 (*9%*)	1 (*2%*)	8 (*7%*)
Black	6 (*25%*)	18 (*25%*)	1 (*17%*)	4 (*13%*)	2 (*6%*)	1 (*9%*)	9 (*14%*)	23 (*20%*)
Mixed race	3 (*13%*)	4 (*6%*)	1 (*17%*)	3 (*10%*)	3 (*8%*)	1 (*9%*)	7 (*11%*)	8 (*7%*)
Other	2 (*8%*)	2 (*3%*)	—	—	—	1 (*9%*)	2 (*2%*)	3 (*3%*)
Total	24	72	6	31	36	11	66	114

Note. T, treatment; C, comparison. Demographic information is based on a sample of $N = 180$.

Table 3
Descriptive statistics of post-scores.

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

Note. T, treatment; C, comparison; KEA, knowledge of engineering applications; EPK, engineering pedagogical knowledge; BEI, beliefs about engineering integration; SEI, self-efficacy for integrating engineering.

Hypothesis Testing

The impact of the Ed+gineering cross-disciplinary model on 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 reflecting collaboration number was used to account for a potential differential effect of the collaborations.

Table 4 summarizes the results of the hypothesis testing. The hypotheses indicate a positive impact of Ed+gineering on preservice teachers' KEP, EPK, BEI, and SEI, after controlling for the pre-test scores. The expected direction of these hypotheses (alternative form) was based on prior empirical evidence in this area. The second column in Table 4 indicates the conclusion of the hypothesis testing. The ANCOVA 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 $H4_a$, suggesting no significant impact of Ed+gineering on BEI.

Figure 2 illustrates the adjusted means for each response variable in treatment and comparison groups and the *p* values for each test. Our findings revealed that the Ed+gineering participants reported higher EPK, KEA, and SEI than students in the comparison group. The hypothesis about the influence of Ed+gineering on preservice teachers' BEI was not supported.

We also examined whether the effects of the intervention (Ed+gineering cross-disciplinary model) differed across collaborations. The interaction term involving collaboration type and type of intervention (treatment or comparison) was significant for EPK ($p < 0.05$, $d = 0.21$), KEA ($p < 0.05$, $d = 0.28$), and SEI ($p < 0.030$, $d = 0.19$). Further exploration of the effects by collaboration revealed that the differences between treatment and comparison groups were larger in

Table 4
Summary of hypothesis testing.

Findings by hypothesis	Support
H1$_a$. The Ed+gineering cross-disciplinary model has a positive influence on preservice teachers' KEP, $F(1, 177) = 12.433$, $p < 0.01$, $d = 0.26$, after controlling for their incoming value (KEPpre = 3.153).	Full
$H2_a$. The Ed+gineering cross-disciplinary model has a positive influence on preservice teachers' EPK, $F(1, 176) = 7.073$, $p < 0.01$, $d = 0.20$, after controlling for their initial knowledge (EPKpre = 3.155).	Full
$H3_a$. The Ed+gineering cross-disciplinary model has a positive influence on preservice teachers' BEI, $F(1, 155) = 0.793$, $p = 0.374$, $d = 0.07$, after controlling for their initial beliefs (BEIpre = 4.287).	No
$H4_a$. The Ed+gineering cross-disciplinary model has a positive influence on preservice teachers' SEI, $F(1, 155) = 5.959$, $p = 0.016$, $d = 0.19$, after controlling for their initial self-efficacy (SEIpre = 3.646).	Full

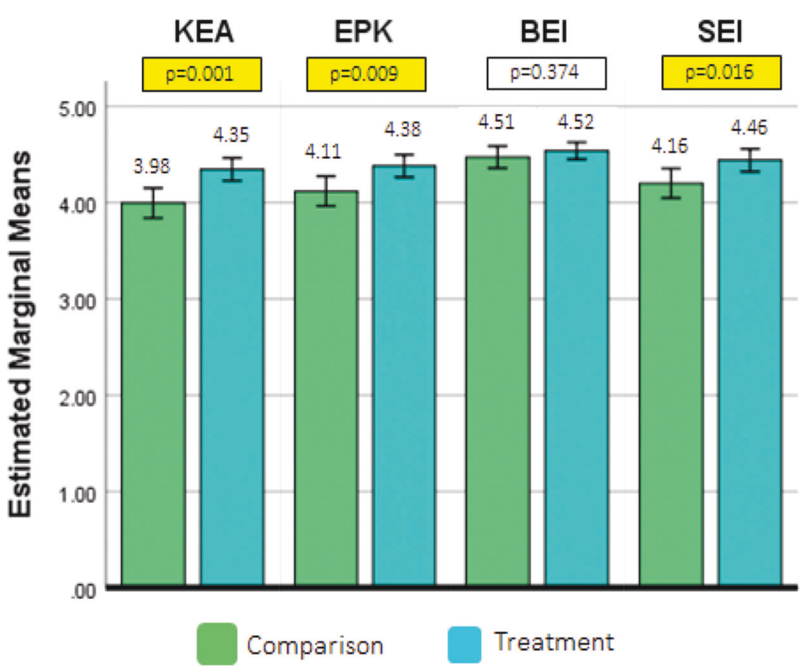

Figure 2. Error bars for adjusted means of each response variable. *Note*. KEA, knowledge of engineering and applications; EPK, engineering pedagogical knowledge; BEI, beliefs about engineering integration; SEI, self-efficacy for integrating engineering. Significant differences are shown in yellow.

collaboration one than in the other two collaborations in all three variables. However, these results should be treated 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. *Post hoc* analysis also revealed that preservice teachers who self-identified as White or Caucasian showed higher average values in the EPK post-test overall ($p < 0.05$) 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 pre-test values capturing the incoming levels of the response variables was implemented to address the potential effect of selection bias. The data are based on 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 data to address this limitation, including observational and qualitative data from focus groups and individual reflections. Additional quantitative data are also being collected to increase the power of statistical analyses.

Discussion

This study's primary goal was to investigate the impact of Ed+gineering on preservice teachers' perceived knowledge and attitudes towards engineering integration. Ed+gineering partners education and engineering students in small cross-disciplinary teams to plan and deliver culturally responsive engineering lessons to upper elementary school students. Empirical evidence has previously shown that preservice teachers benefit from partnering with engineering students as a strategy to introduce engineering content in pre-college environments (Bers & Portsmore, 2005; Fogg-Rogers et al., 2017; Wendell, 2014). 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 preservice teachers' knowledge of engineering practices, engineering pedagogical knowledge, beliefs about engineering integration, and self-efficacy for integrating engineering.

The results suggest that, on average, preservice teachers exposed to the Ed+gineering cross-disciplinary model perceived higher levels of knowledge of engineering practices, engineering pedagogical knowledge, and self-efficacy for integrating engineering than preservice teachers in the comparison group. 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 preservice teachers' 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 (Rich et al., 2017). In conclusion, participation in Ed+gineering positively impacted preservice teachers' perceived knowledge and self-efficacy for engineering integration. Since self-efficacy has been associated with teachers' instructional decisions (Bandura, 1989b), we expect Ed+gineering participants to be more likely than non-participants to integrate engineering content in their classrooms. 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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