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Predicting Engineering Integration in K-12 from the Perspective of Pre-Service Teachers*

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The integration of engineering content at the pre-college level is gaining global traction as a strategy to improve learning outcomes and to promote inclusion and diversity in STEM (Science, Technology, Engineering, and Mathematics). Preservice teacher (PST) programs have become natural insertion points for integration efforts by providing future K-12 teachers with the resources and preparation to teach engineering as part of their academic preparation. There is a need to understand the socio-cognitive mechanisms by which teacher preparation programs can help teachers to integrate engineering in their future classrooms. This work examines how an innovative cross-disciplinary program impacted important social-cognitive drivers of engineering integration. We used mediation analysis to understand a successful pathway to engineering integration as a result of exposure to a cross-disciplinary collaboration with engineering students. This study revealed how participation in the program as part of their academic preparation increased PSTs' confidence to teach engineering and their beliefs about the importance of engineering content, which in turn, increased their intention to integrate engineering in the classroom.

Keywords: Engineering education; engineering integration; K-12 education; cross-disciplinary teams

1. Introduction

The most recent Science Technology Engineering and Math (STEM) national directives documented by the Next Generation Science Standards (NGSS) and the National Research Council's guidelines for K-12 education highlight the need to embed engineering content into pre-college programs as a vehicle to prepare future generations to be competitive in the global market [1–3]. Research studies examining the inclusion of engineering in primary and secondary school programs report benefits in student engagement, learning and achievement, interest in engineering and science, and pursuit of STEM careers [4–7]. Despite the need and potential benefits of engineering education for K-12 students, the pathways towards integrating engineering content in elementary and secondary classrooms remain largely unexplored. Previous evidence suggests that teachers' lack of familiarity and confidence to teach engineering are critical barriers to integration [8, 9], but there is a lack of understanding of effective mechanisms that help address these barriers. This research advances knowledge in precollege engineering education by examining a pathway to engineering integration using a large cross-disciplinary collaboration between education and engineering disciplines aimed at increasing preservice teachers' preparation and self-efficacy by exposing PSTs to scaffolded mastery experiences as part of their courses. We examined how the collaboration influenced PSTs through changes in their self-efficacy to teach engineering and beliefs about engineering integration.

The potential benefits of early exposure to engineering can only be achieved if teachers have the knowledge and attitudes needed to integrate engineering [10]. Teacher preparation programs are natural insertion points for engineering integration efforts. These programs can provide future teachers with the content, resources, and opportunities to learn engineering content and pedagogical knowledge in a low-risk environment, while fostering positive attitudes and beliefs about engineering integration. From the socio-cognitive perspective, a lack of confidence and preparation to engage students in engineering design activities can hinder teachers' abilities to integrate engineering [11–14]. Teachers' attitudes and beliefs about engineering are known to influence their decisions and actions associated with future engineering integration [15]. Thus, examining how teacher preparation programs can help influence preservice teachers' attitudes and beliefs about engineering education is key to achieving engineering integration.

This research contributes to the engineering education body of knowledge by examining a pathway to engineering integration in K-12 settings from a social-cognitive perspective. We investigate how Ed+gineering, a large cross-disciplinary collaboration between education and engineering disciplines, influences preservice teachers' intention to

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integrate engineering through its effect on cognitive and attitudinal factors.

2. Literature Review

Prior research suggests integrating engineering content in STEM instruction requires high-quality training and development programs for teachers [16–18]. As a response to this need, a growing number of programs have focused on developing the knowledge and skills required for teachers to integrate engineering into STEM instruction [4, 9, 19–27]. Preparing teachers to integrate engineering requires developing relevant pedagogical knowledge, basic domain knowledge [16, 28, 29], and positive attitudes towards engineering education [30]. Prior research examined novel and interdisciplinary ways to expose preservice and in-service teachers to engineering through partnerships with university engineering students, university STEM faculty, and practicing professional engineers. Bers and Portsmore [31] wrote about their experience partnering preservice early childhood education majors with engineering students to create and implement robotics lessons with children. Tank and colleagues [32] partnered STEM faculty from education and engineering to jointly plan and implement engineering experiences for preservice teachers. Finally, Kier and Johnson [33] partnered in-service teachers with undergraduate engineering students of color to design and teach culturally responsive engineering lessons to middle school students.

The current study builds on prior work in pre-college engineering education by examining a large cross-disciplinary initiative (Ed+gineering), which partners preservice teachers with undergraduate engineering students to develop instructional materials and teach engineering lessons to elementary students as part of existing academic programs. The intervention differs from prior work in that it was designed within the context of existing courses in engineering and education, using cross-disciplinary student teams, and under the guidance of faculty from both disciplines. This research explores the ways in which participation in this mastery experience drives intention to integrate engineering directly and indirectly through its effect on self-efficacy for engineering integration and beliefs about engineering integration. The focus of the study is on identifying the causal pathways that lead to the PST's intention to integrate through gains in self-efficacy and beliefs as a result of the cross-disciplinary collaboration. These pathways will help reveal key levers that drive teachers' intention to integrate engineering that go beyond the pedagogical and content knowledge acquired.

Prior work from the authors during early program implementation suggests a positive impact of Ed+gineering on intention to integrate when compared to exposure to traditional courses [34]. However, little is known about the factors that drove this increase from the preservice teacher's perspective. This study examines how PSTs' beliefs and self-efficacy to teach engineering influenced intention to integrate because of participating in the cross-disciplinary program. The results help shed light on key social-cognitive and attitudinal levers of engineering integration.

Although research on preservice teachers' intention to integrate engineering is still incipient, it can draw from some related research on integration of technology into teaching. Engineering integration parallels technology integration in that both require PSTs to embrace new educational practices that differ from traditional K-12 instruction. Adopting new approaches has been linked to increased teaching self-efficacy for engineering [35] and technology [36–38]. Prior studies have employed theoretical models, such as the Theory of Planned Behavior [39, 40], TPACK [36, 41, 42], and the Technology Acceptance Model [42] to explore PSTs' intention to integrate technology. Several studies identified self-efficacy [36, 40, 42] and beliefs related to technology integration [39, 40, 42] as significant predictors of intention to integrate technology. Findings from these studies suggest that the relationship between PSTs' knowledge, self-efficacy, and intention to integrate technology is complex and not well understood. Similarly, little is known about the impact of cognitive and attitudinal factors on preservice teachers' intention to integrate engineering. This research aims to close this knowledge gap by developing and testing a predictive model of intention to integrate engineering that identifies key predictors and pathways that lead to PSTs intention to integrate engineering. The predictors are selected based the Career Self-Management Model (CSM) [43]. CSM is an extension of Bandura's social-cognitive theory [44, 45] into the context of professional decisions and actions [43].

3. Theoretical Foundation

This work uses Career Self-Management Model as the theoretical lens to investigate PSTs' beliefs and self-efficacy for engineering integration as precursors of intention to integrate engineering [43]. This model is ideally fit to examine career decisions and intentions in different professional fields, including education. We examine how a cross-disciplinary learning experience in a teacher preparation program affected career-related decisions for teachers, such as the integration of engineering into teaching, by acting on socio-cognitive levers such as teacher's self-efficacy and beliefs. This theory was used to shed light on the relationships between these variables and identify the most relevant pathways that drive gains in intention to integrate.

The Career Self-Management Model (CSM) provides a theoretical foundation that outlines the factors affecting career intentions and actions. This theory examines the individual factors and developmental activities (e.g., participation in training and development) that drive self-efficacy, beliefs about the consequences of one's actions, and intentions related to a professional activity, such as teaching in K-12 settings. CSM [43] extends Bandura's social cognitive theory [44, 45] and Lent and colleagues' social cognitive career theory [46] to explain how individuals manage academic and professional choices in the face of developmental tasks and less predictable events [43]. CSM posits that behaviors associated with career decisions relate to three core constructs: (1) self-efficacy (belief in one's capabilities to perform specific actions), (2) outcome expectations (beliefs about the positive and negative consequences of one's actions), and (3) goals (intentions to engage in a particular activity or attain a certain level of performance). Based on CSM, developmental tasks and activities that involve cognitive development and social learning experiences (such as training and development) drive individual self-efficacy beliefs associated with those tasks, outcome expectations (perceptions about the positive and negative consequences of one's actions), which in turn, drive intentions and actions [46, 47].

This research focuses on preservice teachers' intentions to integrate engineering content in their K-12 classrooms. CSM posits that learning experiences during teacher preparation influence self-efficacy and beliefs by conveying information about personal performance accomplishment, observational modeling, social persuasion, and physiological and affective states [43, 48]. Thus, a PST participating in a scaffolded and socially supported learning experience of designing and implementing an engineering lesson with engineering students and faculty support provides an opportunity to gain confidence to complete that same task autonomously and successfully [43, 47, 49]. Self-efficacy has been linked to actions and attainments by driving individuals to persist in the face of challenges [47]. In the context of this study, the specific career-related actions under consideration relate to the intention to integrate engineering into teaching.

The intervention investigated in this study presents participating preservice teachers with opportunities to enact the expected behaviors in an environment that provides modeling, social persuasion, and the necessary skill and knowledge to integrate engineering in elementary instruction [23, 24]. Participation in the cross disciplinary collaboration afforded PSTs with a scaffolded mastery experience of designing and teaching an engineering lesson as part of a course project, while being supported by engineering students and faculty. Prior studies have shown that engineering interventions for in-service teachers led to increased self-efficacy and beliefs about engineering integration [11, 35]. As suggested by CSM and affirmed in other studies linking self-efficacy and beliefs [e.g., 39], we predict self-efficacy will influence beliefs about engineering integration and intention to integrate engineering. Self-efficacy for engineering integration represents the extent to which PSTs believe in their ability to incorporate engineering into their teaching. Beliefs about engineering integration in K-12 represent PSTs' mental representation of the impact of engineering integration on their students and classroom. Thus, we propose that the learning experience of participating in the cross-disciplinary collaboration with engineering students positively influences the PSTs' intention to incorporate engineering into their classes through its effect on self-efficacy and beliefs associated with engineering integration. Although several empirical studies explored the relationship between these variables in STEM education settings [40, 42, 50, 51], few examined the ways in which engineering education experiences in teacher preparation programs affect intention to integrate from a social-cognitive perspective. This research aims to fill this gap by examining the pathways that lead to intention to integrate through changes in self-efficacy and beliefs about engineering after participation in a collaboration program with engineering.

4. Methods

4.1 Study Context and Sample

Data for this research was collected at a large public urban university in the U.S. Mid-Atlantic region between Fall 2020 and Spring 2022. A sample of 291 students from the university's teacher preparation program agreed to participate in the study. Participating preservice teachers were assigned to treatment (n = 110) and comparison groups (n = 181) based on their course section. All participating courses had two versions (treatment and comparison) with the same learning objectives and similar content. The two conditions differed in that the PSTs in the treatment group completed a cross-disciplinary collaboration project with engineering students as a class project. The collaboration project included an opportunity to design and teach an engineering lesson to an elementary school audience. The comparison group completed the same class using a traditional instructional approach without cross-disciplinary collaboration. As part of their cross-disciplinary class project, PSTs in the treatment group worked with engineering students in small teams of 4–6 participants. Each team worked together to design an engineering challenge, develop the associated instructional materials, and deliver an engineering lesson to elementary and middle school students. There were three cross-disciplinary collaborations with a partnering engineering class. Collaboration A took place in an Educational Foundations course partnering with an Engineering Information Literacy course. Collaboration B partnered an Educational Technology course and a junior level Computational Methods course. Collaboration C involved an Elementary Science Methods course partnering with a Fluid Mechanics course in engineering.

Table 1 describes the overall sample's demographic characteristics regarding gender and ethnicity and the breakdown by collaboration. As in most teacher preparation programs, a majority identified as females (93.8%). Regarding race, 65.3% self-identified as White or Caucasian, 19.5% as Black or African American, 7.6% Hispanic, 4.5% reported mixed race, and 3.1% indicated other ethnicities. The selected sample is representative of the population of preservice teachers in large public urban universities in the Mid-Atlantic region in terms of gender, age, and ethnicity [52].

4.2 Research Design

The protocol for recruitment and data collection was approved by the University's human subjects review board and was in accordance with the ethical standards from the institution. Data were collected at the start of each semester and two weeks before the end through an online survey. The following section presents the operational definition of the variables, the proposed theoretical model, and the research hypotheses.

4.2.1 Variables

Independent Variable.

Exposure to Treatment or Comparison. This independent dichotomous variable classifies students into comparison (0) or treatment group (1).

Mediators. There are two mediator variables: self-efficacy for engineering integration (SEI) and beliefs about engineering integration (BEI). The scales used to assess these variables were adapted from existing instruments [30, 35, 53], incorporating elements of social cognitive theory [44] to measure PSTs' self-efficacy for integrating engineering (SEI) and beliefs about engineering integration (BEI).

Self-efficacy for Engineering Integration (SEI). Self-efficacy refers to an individual's belief about the ability to perform a specific behavior [43]. Self-efficacy for integrating engineering (6 items) measures the extent to which PSTs believe that they can successfully incorporate engineering-based learning into their future teaching. The scale was adapted from Yoon, Evans, and Strobel [53] to fit the content of preservice teachers. A sample item is "I can explain the different phases of the engineering design process." SEI exhibits high internal consistency (α = 0.959). Items are rated on a 5-point Likert scale from 1 (*strongly disagree*) to 5 (*strongly agree*).

Beliefs about Engineering Integration (BEI). Beliefs refer to an individual's mental representations of reality accepted as truth that guide behavior [54]. Beliefs about engineering integration (5 items) assessed PSTs' beliefs about the impact and expected outcomes of integrating engineering in the classroom. The internal consistency of this subscale was α = 0.956. A sample item is "Implementing engineering design problems would add

Table 1. Sample Demographics

	Sample	Comparison (n = 181)			Treatment (n = 110)		
		Collaboration A	Collaboration B	Collaboration C	Collaboration A	Collaboration B	Collaboration C
Gender							
Female	273 (93.8%)	118	10	43	71	16	15
Male	14 (4.8%)	5	2	1	3	2	1
Other	4 (1.4%)	2	0	0	1	0	1
Ethnicity							
White or Caucasian	190 (65.3%)	79	8	37	43	10	13
Black or African American	57 (19.5%)	25	2	3	21	4	2
Hispanic, Latinx, or Spanish	22 (7.6%)	11	1	2	5	1	2
Mixed race	13 (4.5%)	6	0	2	2	3	0
Other	9 (3.1%)	4	1	0	4	0	0

N = 291.

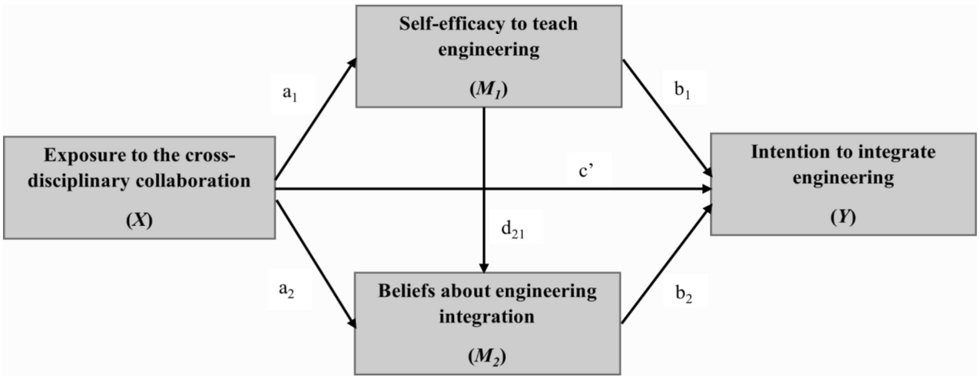

Fig. 1. Proposed Predictive Model of Intention to Integrate Engineering.

value to my classroom." Items are rated on a 5-point Likert scale anchored from 1 (*strongly disagree*) to 5 (*strongly agree*).

Dependent variable.

Intention to integrate engineering (IIE). IIE is defined as PSTs' behavioral intentions to incorporate engineering-based practices once they are in service. IIE was adapted from existing scales [35, 55] and consisted of five self-reported items in a 5-point Likert scale (1 = *strongly disagree* to 5 = *strongly agree*). A sample item is "I plan to help my students understand the science underlying engineering." IIE demonstrates a high level of internal consistency (α = 0.973).

4.2.2 Research Hypotheses

Based on CSM [43], we hypothesize that participation in the cross-disciplinary collaboration with engineering students as part of an academic preparation program drives PSTs to increase their confidence and develop positive attitudes towards engineering integration, which in turn, can have a positive impact on their intention to integrate engineering compared with a traditional approach to teacher preparation. Thus, we predict the impact of the Ed+gineering partnership is positively mediated through an increase in self-efficacy to teach engineering and beliefs about engineering integration. As a result, we propose the following hypotheses in the alternative form:

H_1: Self-efficacy for engineering integration partially mediates the effect of Ed+gineering on the intention to integrate engineering.

H_2: Beliefs about engineering integration partially mediates the effect of Ed+gineering on the intention to integrate engineering.

H_3: Participation in Ed+gineering will have a positive effect on self-efficacy for engineering integration, which in turn enhances beliefs about engineering integration and ultimately increases intention to integrate engineering.

H_4: Participation in Ed+gineering will have an overall positive effect on intention to integrate engineering.

Fig. 1 represents the proposed theoretical model tested in this study. It consists of a serial multiple mediation model that examines the predictive pathway to intention to integrate engineering. The diagram includes the coefficients corresponding to the relationships under investigation, which the model will reveal in direction and magnitude. We studied the indirect impact through self-efficacy and beliefs about engineering integration, the direct impact, as well as the total effect. Based on CSM, we posed an a priori assumption that SEI drives BEI, which in turn affects IIE.

Table 2 shows the internal consistency coefficients and Pearson correlation indexes among mediators and the dependent variable estimated from the overall sample. The three aggregated constructs show strong evidence of reliability, as displayed by their Cronbach's Alpha (α).

4.3 Results

We examined the impact of a cross-disciplinary collaboration (exposure, X) on preservice teachers' intention to integrate engineering using a serial multiple mediator model [56]. The proposed model includes an independent dichotomous categorical variable representing exposure to either treatment or comparison, a dependent variable

Table 2. Internal Consistency and Correlation Coefficients

Variable	Items	A	Correlation coefficient		
			1	2	3
IIE	5	0.973	_	0.807	0.865
SEI	6	0.959		_	0.740
BEI	5	0.956			_

N = 291.

measuring intention to integrate engineering (IIE), and two mediators. The model predicts the effect of the intervention on IIE through a causal sequence of SEI and BEI using CSM as the theoretical foundation to the proposed relationships and hypotheses.

Following the procedures for serial multiple mediator models proposed by Hayes [56], we utilized a regression approach based on Ordinary Least-Square (OLS) criterion and bootstrapping sampling to determine the statistical significance of the model effects. To account for a slight deviation from normality, we adopted a non-parametric approach with percentile confidence intervals generated from 10,000 bootstrap samples. Bootstrapping is a resampling method used in mediation analysis to estimate confidence intervals for all indirect effects, which "yield to inferences that are more likely to be accurate than when normal theory approach is used" [56, p. 98]. Thus, we can overlook the normality assumption to analyze the data using this method since bootstrapping provides a robust estimation of the indirect effect of mediation when normality cannot be assumed. Bootstrap confidence intervals of indirect effects are interpreted based on the zero location. When zero is outside the bootstrap confidence interval at a given confidence level, an indirect effect is considered statistically significant [56].

We posed a double serial mediator model to examine how the intervention influenced intention to integrate directly and indirectly through its effect on self-efficacy and beliefs. The statistical model corresponds to Model 6 in the mediation analysis approach described in Hayes [56]. This model with two mediators includes one direct effect and three indirect effects of the cross-disciplinary collaboration on PST's IIE. The three indirect paths account for the effects of the intervention on IIE through each mediator (SEI and BEI) and the effect of the intervention on SEI, its subsequent effect on BEI, which in turn influences IIE. In the present study, we focused specifically on quantifying these indirect effects and the total effect's coefficient to understand the impact of the program through changes in PSTs self-efficacy.

Fig. 1 illustrates the relationships between the variables of interest. Estimates of the indirect effects are based on the products of regression coefficients involved in specific paths linking exposure to the intervention and IIE. The indirect effect of the independent variable on IIE through SEI is determined by the coefficient a_1b_1 (H_1). The product of a_2b_2 indicates the indirect effect of the independent variable on IIE mediated by BEI (H_2). The product of $a_1d_{21}b_2$ indicates the sequential indirect effect of the cross-disciplinary collaboration on IIE through SEI and BEI in serial (H_3). The sum of direct and all indirect effects represents the total effect of the exposure to the treatment on IIE (H_4).

Table 3. Descriptive Statistics of the Mediating Model Variables

		Y	M1	M2	Y
		IIE	**SEI**	**BEI**	**Adjusted**
Treatment (X1)	*M*	4.42	4.32	4.57	4.17
	SD	0.93	0.89	0.86	
Comparison (X0)	*M*	4.01	3.77	4.28	4.16
	SD	1.10	1.03	0.99	
Complete sample	*M*	4.17	3.98	4.39	
	SD	1.06	1.01	0.95	

N = 291.

The analysis relied on bootstrap estimates and confidence intervals to determine the statistical significance of the indirect effects following Meule's recommendation [57]. There is growing consensus suggesting bootstrapping superior to the causal steps approach to mediation analysis as it makes no assumptions about normality and reduces the likelihood of Type I error [57, 58]. Because the independent variable is dichotomous (0 = comparison, 1 = treatment), non-standardized beta coefficients were interpreted [56]. The PROCESS package for R was used for data analysis.

Hypotheses about the effect of the cross-disciplinary collaboration on IIE directly and indirectly through its effect on SEI and BEI were tested using a two serial multiple mediator model. Table 3 displays descriptive statistics of the variables in the model, including the adjusted mean of IIE for both treatment and comparison groups.

Table 4 summarizes key statistics, including estimated coefficients (*Coeff.*), standard errors (*SE*), and significance levels. R-square and F-test are also reported for each model of consequent variables. According to the coefficients in Table 4, the inclusion of the two mediators in serial increased the proportion of variance of IIE explained by the statistical model.

The hypothesized mediating effects of SEI and BEI were determined based on 95% bootstrap confidence intervals generated from 10,000 bootstrap samples (Table 5). The confidence interval of the indirect effect of the cross-disciplinary collaboration on IIE through SEI is significantly different from zero (a_1b_1 = 0.208, *LLCI* = 0.103, *ULCI* = 0.334), which supports H_1. Meanwhile, the confidence interval of the single mediation of BEI (a_2b_2 = –0.066, *LLCI* = –0.152, *ULCI* = 0.017) suggests a non-significant indirect effect on IIE through this path (H_2). The indirect effect of participation in the cross-disciplinary collaboration on IIE through SEI and BEI in a two serial mediation was found positive and significant ($a_1d_{21}b_2$ = 0.253, *LLCI* = 0.145, *ULCI* =

Table 4. Summary Information of the Serial Multiple Mediator Model

		Consequent										
		M_1 (SEI)				M_2 (BEI)				Y (IIE)		
Antecedent		***Coeff.***	***SE***	***p***		***Coeff.***	***SE***	***p***		***Coeff.***	***SE***	***p***
X (Exposure)	a_1	0.544	0.118	<0.001	a_2	–0.101	0.080	0.207	c'	0.006	0.057	0.906
M_1 (SEI)		–	–	–	d_{21}	0.711	0.038	<0.001	b_1	0.382	0.040	<0.001
M_2 (BEI)		–	–	–		–	–	–	b_2	0.654	0.042	<0.001
Constant	iM_1	3.772	0.072	<0.001	iM_2	1.599	0.153	<0.001	Iy	–0.232	0.129	0.073
		$R^2 = 0.067$ $F(1, 289) = 21.06$ $p < 0.001$				$R^2 = 0.551$ $F(2, 288) = 177.07$ $p < 0.001$				$R^2 = 0.810$ $F(3, 287) = 410.14$ $p < 0.001$		

N = 291.

Table 5. Summary of Indirect Effects on IIE from Bootstrapping Resampling

	Bootstrapping estimates		Bootstrapping 95% confidence interval	
Effect	***Coefficient***	***SE***	**Lower**	**Upper**
Indirect effect Exposure > SEI > IIE	0.208	0.058	0.103	0.334
Indirect effect Exposure > BEI > IIE	–0.066	0.043	–0.152	0.017
Indirect effect Exposure > SEI > BEI > IIE	0.253	0.057	0.145	0.370
Total indirect effect	0.395	0.111	0.173	0.609

N = 291, *k* =10,000.

Table 6. Total Effect of the Serial Multiple Mediator Model

Effect	***Coefficient***	***SE***	***P***	***LLCI***	***ULCI***
Total effect X (Exposure) on Y (IIE)	0.402	0.125	0.001	0.154	0.649

Table 7. Summary of Hypothesis Testing

Hypothesis (alternative form)	**Result**
H_1. Self-efficacy for engineering integration partially mediates the effect of Ed+gineering on intention to integrate engineering	Supported
H_2. Beliefs about engineering integration partially mediate the effect of Ed+gineering on intention to integrate engineering	Not supported
H_3. Participation in Ed+gineering will have a positive effect on self-efficacy for engineering integration, which in turn enhances beliefs about engineering integration and ultimately increases intention to integrate engineering.	Supported
H_4. Participation in Ed+gineering will have an overall positive effect on intention to integrate engineering	Supported

0.370), supporting H_3. The total indirect effect of Ed+gineering on IIE estimated from bootstrapping was also positive and different from zero, as indicated by the bootstrap confidence interval (*coeff.* = 0.395, *LLCI* = 0.173, *ULCI* = 0.609).

The statistical test results of the total effect of exposure to the treatment on intention to integrate engineering are shown in Table 6. Based on these findings, the total effect of Ed+gineering on IIE was statistically significant and positive (*total effect* = 0.402, p = 0.001), indicating that PSTs in the treatment group reported higher overall intention to integrate engineering than their counterparts in the comparison group after participating in the cross-disciplinary collaboration. Therefore, H_4 was supported. Table 7 summarizes the results of the hypothesis test.

Results indicate that, overall, the two serial mediator model of IIE is significant and explains a large percent of the variance ($R^2 = 0.810$; $F(3, 287) = 410.14$, $p < 0.001$). Specifically, SEI accounts for a sizable proportion of variance in IIE between treatment and comparison groups. PSTs who were part of the treatment group, on average, reported higher levels of self-efficacy to integrate engineering than PSTs in the comparison group, and this perceived self-efficacy was associated with a greater intention to integrate engineering. Also, exposure to Ed+gineering indirectly influences IIE through both SEI and BEI in serial, with self-efficacy influencing beliefs, which in turn affects intention to integrate. This suggests participants of the cross-disciplinary collaboration reported higher levels of self-efficacy than PSTs in the comparison group, which was associated with stronger self-reported beliefs about engineering integration, which in turn resulted in a greater intention to integrate engineering. The statistically significant total effect of Ed+gineering on PSTs' IIE indicates that, overall, participants and non-participants of the cross-disciplinary partnership differed by *0.402* units in their reported IIE. Thus, PSTs who collaborated with engineering students reported higher average intentions to integrate engineering than those exposed to the traditional version of the course. The larger magnitude of the total indirect effect compared to the direct effect suggests that participation in the cross-disciplinary collaboration increases overall intention to integrate engineering mostly indirectly through increases in self-efficacy and beliefs as mediators.

5. Discussion

Multiple studies [e.g., 59–61] have found that both preservice and in-service elementary educators lack engineering self-efficacy and teaching efficacy that may be necessary to successfully integrate engineering content, skills, and processes into their classrooms. Framed by the Career Self-management Model (CSM), this paper explored an approach to improve PSTs' readiness to integrate engineering. We explored the impact of a cross-disciplinary collaboration model on intention to integrate engineering through its effect on self-efficacy and beliefs about engineering integration from the preservice teacher perspective. The positive results obtained in the present study suggest that cross-disciplinary partnerships between preservice teachers and engineering students can help support engineering integration efforts in K-12 settings.

Our findings provide empirical support that participation in the cross-disciplinary partnership with engineering students and faculty drove PSTs to increased levels of confidence to teach engineering and beliefs about the benefits of integrating engineering. In turn, the heightened levels of confidence led to increases in intention to integrate engineering in the classroom. These results provide evidence of the benefits of exposing PSTs to cross disciplinary and hands-on engineering education opportunities during their academic preparation. The intervention exposed PSTs to a scaffolded learning experience of designing and delivering an engineering lesson. This learning experience afforded PSTs with the opportunity to work with fellow PSTs, engineering students, and faculty to develop expertise and confidence to implement engineering education in an authentic low-risk environment. The intervention also led to increases in beliefs about the integration of engineering in K-12 settings. The findings related to the impact of the intervention on self-efficacy align with results from Perkins Coppola [11] in which PSTs taught engineering lessons to K-5 students and saw significant increases in various subcategories (i.e., engineering pedagogical knowledge, engagement, disciplinary) of self-efficacy. Our results extend Perkins Coppola's work [11] by drawing causal connections between program participation, self-efficacy, and intention to integrate.

This work was motivated by the assertion that "elementary educators are largely untrained in the 21st century skills of [. . .] engineering" [35, p. 1]. Currently, it is common for PSTs' first exposure to engineering or engineering education to occur in upper-level courses within their teacher preparation program, if even at all [62]. Until recently, most elementary teacher preparation programs have not introduced preservice teachers to engineering [10]. Some recent efforts have introduced engineering as a pedagogical strategy within science methods courses but failed to provide opportunities for preservice teachers to interact with individuals in the engineering field or to practice teaching engineering content in authentic contexts. This research addresses the call by Tschannen-Moran and colleges [63] and others [e.g., 64, 65] for teacher preparation programs to provide "more opportunities for actual experiences with instruction and managing children" that constitute mastery experiences [66, p. 235] and to forge partnerships with faculty in engineering [67]. The Ed+gineering program exemplifies a mastery experience where preservice teachers can plan, develop, and teach an engineering lesson in an authentic environment in collaboration with engineering students [68]. Our findings indicate that Ed+gineering participants report an increased intention to integrate engineering further reinforcing the idea that socially supported mastery experiences teaching children are particularly important for teachers working in content areas such as engineering, where they do may not feel as confident. Elementary student engagement while participating in hands-on field-based engagement opportunities has also been tied to preservice teachers' increases in enthusiasm, and stronger values and beliefs related to the subject area [69]. Preservice teachers in the Ed+gineering program had the opportunity to engage with elementary students by teaching them an engineering lesson.

Our results differ from studies on technology integration in that we did not find a direct relationship between the collaborative experience of teaching an engineering lesson and beliefs about engineering integration [70]. One possible explanation of this finding is that participants had very positive beliefs about the importance of engineering before participating in the program, leaving little room for increases to take place as a result of participation.

There are some limitations that affect the generalizability of this study. First, this research did not randomly assign participants to treatment and comparison groups because it had to rely on existing course sections for implementation of the intervention. However, we did not find pre-existing differences between treatment and comparison groups in the variables of interest for this study, suggesting that both groups were comparable.

Second, the use of self-report data to assess the intervening and response variables could have been affected by some level of social desirability. This issue was addressed by incorporating data from a comparison group that used the same type of assessment. We found no pre-existing differences between treatment and comparison participants in the variables of interest suggesting that both groups were comparable on the variables of interest before conducting the research.

Results from this research offer insight into how teacher preparation programs can help infuse in future teachers the skills and confidence to support the integration of engineering in the classroom. The findings also show the potential of using cross-disciplinary teams where preservice teachers learn in a supportive social context and build knowledge by interacting with engineering students and faculty. Our findings suggest cross-disciplinary partnerships with engineering students offer promise as a low-risk teaching environment [71, 72], where preservice teachers can learn and exercise new pedagogical approaches in engineering, such as the engineering design process in a supported setting. The intervention investigated in this study provides preservice teachers with the opportunity to learn and teach in a socially supported setting, with scaffolded activities, expert feedback, and faculty and peer support.

6. Conclusion

This study examined how a cross-disciplinary collaboration influenced preservice teachers' intentions to integrate through its impact on self-efficacy for teaching engineering and personal beliefs about engineering integration. Self-efficacy was both a direct and an indirect mediator (through beliefs) of the effect of Ed+gineering on preservice teachers' intention to integrate engineering in their classrooms. This result suggests that preservice teacher education programs can support the development of skills and confidence, particularly through the application of the engineering design process, which can help facilitate the integration of engineering in the K-12 context.

Future studies can look at the impact of multiple exposures to engineering that start within teacher preparation programs and continue with professional development activities through teachers' professional careers. There is also great potential for research exploring specific contextual barriers and enablers of successful engineering integration in the K-12 setting. This field of study can also benefit from using additional indicators of intention to integrate such as preservice teachers' lesson plans or classroom observation protocols. Lesson plans can provide additional evidence of intention to teach engineering and insight into teachers' levels of competency.

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