Enhancing Elementary Pre-service Teachers' STEM Integration: Perceptions, Self-Efficacy, and Behavioral Intentions Through Experiential Learning in a Mathematics Methods Course.

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Abstract: The increasing demand for STEM-literate citizens requires a systematic preparation of elementary teachers who can effectively integrate science, technology, engineering, and mathematics from the earliest grades. In this study we address the critical gap in elementary STEM teacher preparation by implementing and evaluating STEM activities within a mathematics methods course in a US teacher preparation program. We used an experiential learning approach to expose and engage Elementary Pre-Service Teachers (EPSTs) in structured STEM activities designed to enhance their confidence and pedagogical readiness. Results indicate that after engaging in STEM activities, EPSTs demonstrated significantly higher levels of confidence and preparedness to integrate STEM activities in their future lessons. Specifically, our goal was to contribute new knowledge about how experiential learning transforms elementary pre-service teachers' acceptance of STEM integration, revealing that structured hands-on experiences are more effective than traditional lecture-based approaches in developing STEM self-efficacy. EPSTs recognized the value of integrating STEM activities within their lessons as a strategy to enhance conceptual understanding in mathematics and science topics.

Keywords: Elementary Pre-service Teachers; STEM; Experiential Learning; Teacher Preparation; Self-Efficacy.

INTRODUCTION

STEM education represents an integrated approach to teaching science, technology, engineering, and mathematics that mirrors real-world problem-solving and innovation processes (Kelley & Knowles, 2016). In today's rapidly evolving technological society, STEM literacy has become essential for informed citizenship, economic competitiveness, and addressing complex global challenges such as climate change, healthcare innovation, and sustainable development (NSF, 2020). The importance of STEM education is particularly relevant during elementary years, as students' attitudes toward STEM fields and self-efficacy beliefs are largely formed during these foundational years (Master et al., 2017). Early exposure to integrated STEM experiences capitalizes on children's natural curiosity, establishes crucial conceptual foundations, and fosters critical thinking skills, spatial reasoning, and positive dispositions toward mathematics and science that persist throughout their academic trajectories (Bers et al., 2021; Hebebci & Usta, 2022).

Despite the recognized importance of early STEM education, elementary teachers face significant challenges in implementing integrated STEM instruction. Many teachers in grades K–6 report feeling underprepared and lacking confidence in both STEM content knowledge and pedagogical approaches (Margot & Kettler, 2019). These challenges are compounded by limited disciplinary exposure during their own K–12 education and insufficient preparation in teacher education programs that traditionally prioritize literacy and general pedagogy over disciplinary integration (Stohlmann et al., 2012).

Existing research reveals that traditional preparation approaches relying heavily on theoretical coursework without hands-on experiences are insufficient for developing the confidence and competence needed for effective STEM integration (Nadelson et al., 2013). While studies have examined professional development benefits for in-service teachers (Tomas et al., 2019), limited research addresses how experiential learning within pre-service preparation programs can enhance STEM self-efficacy and integration skills. For example, Bursal and Paznokas (2006) found that inquiry-based science experiences increased pre-service teachers' science teaching self-efficacy, and McKinnon and Lamberts (2014) reported that engineering design challenges strengthened understanding of integrated STEM pedagogies and willingness to implement them in future classrooms.

Our study addresses these gaps by examining how experiential learning within a teacher preparation program can enhance elementary pre-service teachers' (EPSTs) attitudes, self-efficacy, and behavioral intentions toward STEM integration. Using a convergent parallel mixed-methods design, we investigated changes in EPSTs' confidence, value perceptions, and implementation intentions following participation in structured STEM activities, guided by the following research question: How does EPSTs' participation in structured STEM activities within an experiential learning framework influence their attitudes, self-efficacy, and intentions to integrate STEM in their future classroom instruction? This overarching question was examined by (a) analyzing changes in EPSTs' confidence and perceived ability to implement STEM activities, (b) investigating shifts in value perceptions and expectations regarding STEM integration, and (c) exploring the development of behavioral intentions to incorporate STEM approaches in future teaching practice.

LITERATURE REVIEW AND THEORETICAL PERSPECTIVES

Our study is grounded in an integrated framework combining experiential learning theory, technology acceptance models, and self-efficacy theory. This multi-theoretical approach provides a comprehensive lens for understanding how structured hands-on experiences influence pre-service teachers' attitudes and behavioral intentions toward STEM integration.

Experiential Learning Theory

Experiential Learning (EL) represents a holistic educational philosophy that emphasizes the central role of experience in knowledge construction and skill development (Kolb, 2014). Grounded in social constructivist principles (Vygotsky, 1978) and Piaget's (1976) constructivist theory, meaningful learning occurs when learners actively engage with materials, ideas, and social contexts through authentic participation. Kolb's (1984) four-stage cycle—concrete experience, reflective observation, abstract conceptualization, and active experimentation—provides the pedagogical framework for the STEM activities implemented in this study.

The integration of experiential learning with social learning theory (Bandura, 1977) further explains how EPSTs develop STEM teaching competencies through observational learning, modeling, and guided practice, acquiring both technical skills and the self-efficacy beliefs necessary for effective STEM integration. This social dimension is particularly relevant in STEM education, where collaborative problem-solving and peer interaction are essential components of authentic practice. Research supports the effectiveness of such approaches: Tomas et al. (2019) demonstrated that hands-on STEM experiences increased EPSTs' teaching confidence and deepened their understanding of scientific practices, while Bursal and Paznokas (2006) found that experiential approaches improved both content knowledge and pedagogical understanding. Collectively, these experiences were designed to develop what Shulman (1987) conceptualized as pedagogical content knowledge—the intersection of content knowledge, pedagogical knowledge, and knowledge of students and curriculum.

Technology Acceptance Model Applied to STEM Integration

The Technology Acceptance Model (TAM) provides valuable frameworks for understanding how individuals adopt and integrate new technologies and pedagogical approaches in educational contexts (Venkatesh et al., 2003). Applying the acceptance theory to STEM integration offers a novel perspective for understanding how EPSTs develop intentions to use STEM approaches in their future practice, contributing new knowledge about the psychological and social factors that influence STEM adoption in elementary education. This theoretical lens brings a unique perspective to elementary STEM teacher education by focusing not just on skill development, but on the acceptance processes that ultimately determine whether pre-service teachers will implement STEM approaches in their classrooms. Unlike previous research that has primarily examined STEM teacher education through self-efficacy or content knowledge frameworks, the acceptance theory perspective highlights the complex interplay of performance expectations, effort expectations, social influences, and facilitating conditions that shape EPSTs' behavioral intentions–i.e., understood as the motivation or wiliness to implement or integrate STEM activities. Venkatesh et al.'s (2003) Unified Theory of acceptance and use of technology identify four key determinants of acceptance and use: performance expectancy, effort expectancy, social influence, and facilitating conditions.

In the context of STEM education and this study, performance expectancy relates to EPSTs' beliefs about how STEM integration will enhance their teaching effectiveness, while effort expectancy concerns their perceptions of the ease of implementing STEM activities. Social influence encompasses the degree to which EPSTs believe important others expect them to use STEM approaches, and facilitating conditions refer to the organizational and resource support available for STEM implementation.

Self-Efficacy Theory

Self-efficacy, defined as individuals' beliefs in their capabilities to organize and execute courses of action required to produce given attainments (Bandura, 1997), represents a fundamental construct in understanding human motivation and behavior. In education, self-efficacy beliefs significantly influence teachers' instructional decisions, persistence in facing challenges, and overall effectiveness in implementing innovative pedagogical approaches (Emiru & Gedifew, 2024). Self-efficacy is particularly crucial for elementary teachers implementing STEM education because they must feel confident in their ability to integrate multiple disciplines while maintaining age-appropriate instruction and managing diverse learning needs. Research consistently demonstrates that teachers with higher self-efficacy are more likely to attempt innovative teaching methods, persist through implementation challenges, and create engaging learning environments for their students (Tschannen-Moran & Hoy, 2001).

Elementary STEM education presents unique self-efficacy challenges because teachers must feel competent across multiple disciplines while understanding how to create meaningful connections between science, technology, engineering, and mathematics concepts. Teachers with low STEM self-efficacy may avoid implementing interdisciplinary activities, thereby limiting their students' exposure to integrated STEM experiences during critical developmental years (Palmer et al., 2015). The development of STEM self-efficacy among EPSTs is therefore essential for addressing the persistent gap in elementary STEM education quality and accessibility. Bandura (1997) identified four primary sources of self-efficacy: mastery experiences, indirect experiences, verbal persuasion, and physiological and emotional states. Our study's experiential learning approach primarily targets mastery experiences—the most powerful source of self-efficacy—by providing EPSTs with successful hands-on STEM implementation experiences.

The integration of these three theoretical frameworks provides a comprehensive understanding of how experiential learning interventions can systematically develop EPSTs' self-efficacy beliefs and acceptance of STEM integration, ultimately preparing more confident and competent elementary STEM educators.

METHODS

Research Design and Rationale

We considered a convergent parallel mixed-methods design (Creswell & Plano Clark, 2017) to comprehensively examine changes in EPSTs' STEM attitudes, self-efficacy, and behavioral intentions. This design was chosen because quantitative measures alone cannot capture a holistic experiences and meaning-making processes that occur during experiential learning. Similarly, if we relied solely on qualitative data, we would lack sufficient evidence to demonstrate systematic changes across the participant population. The integration of quantitative surveys with qualitative interviews allowed for triangulation of findings and provided both breadth and depth in understanding the intervention's impact. We recognize that in our study, we only considered a single-group pre-post design without a control group, which limit our ability to generalize and make strong causal inferences. However, we considered our study as an opportunity to obtain preliminary evidence about the potential impact of experiential learning approaches in STEM teacher preparation.

Participants and Demographics

The participant of our study consisted of 75 undergraduate EPSTs enrolled in a teacher preparation program at a Hispanic-Serving Institution (HSI) in south-central United States. A power analysis in G*Power indicated that this sample size was adequate for detecting medium effect sizes ($d = 0.50$) with 80% power at $\alpha = 0.05$ for paired t-tests. Participants EPSTs ranged in age from 19 to 25+ years, with 67 females (89%) and 8 males (11%), as considered by their biological sex. Many participants (53%) were enrolled in bilingual education programs, reflecting the institution's focus on serving diverse student populations. Notably, 89% of participants reported no prior STEM coursework experience, and 64% identified as first-generation college students. EPSTs were recruited through convenience sampling (Creswell & Guetterman, 2024) from required mathematics methods courses across two academic semesters.

Data Collection

The measurement instrument used was systematically developed through adaptation and validation of existing instruments (Abbad, 2021; Ensign, 2017; Gado et al., 2006). The final 22-item survey measured six specific constructs: self-confidence and ability, value and enjoyment of STEM, performance expectancy, effort expectancy, social influence, and behavioral intention. Items were measured using a five-point Likert scale (1 = completely disagree, 5 = completely agree). Cronbach's alpha coefficients for the six constructs ranged from .78 to .91, indicating acceptable to excellent internal consistency reliability.

In addition, semi-structured interviews were conducted with 8 volunteer EPSTs, lasting approximately 20-30 minutes each and video-recorded for analysis. Interview questions explored participants' experiences with the STEM activities, perceptions of STEM's value in elementary education, and intentions for future implementation (see Table 8 for complete interview protocol). Data were collected between Spring 2023 and Spring 2024 across two academic semesters to ensure consistency and replication of findings. Pre-intervention surveys were administered during the first week of each semester, with post-intervention surveys collected during the final week after completion of all STEM activities.

STEM Activities

In this study, we focused on developing EPSTs' pedagogical skills for teaching mathematics within STEM contexts that they could promote in their future classrooms. Since pre-service teachers often exhibit mathematics anxiety (Itter & Meyers, 2017), we designed activities to address these concerns by demonstrating the usefulness and accessibility of STEM integration for elementary students. Five structured STEM activities were systematically implemented across each 14-week semester, spaced approximately 2-3 weeks apart to allow for reflection and integration of learning. Each activity incorporated pre- and post-activity discussions designed to facilitate explicit connections between hands-on experiences and mathematical concepts. All activities were aligned with Kolb's (1984) experiential learning cycle and elementary mathematics standards.

Corn tortilla making (Haciendo tortillas de maíz)

This activity required EPSTs to make corn tortillas from scratch using a mechanical tortilla-maker machine while applying mathematical concepts of ratios and proportions (See Figure 1). The use of the machine was modeled by the instructor to demonstrate proper procedures and safety protocols. Mathematical learning objectives included understanding ratios, proportional reasoning, and measurement concepts through authentic application. To create quality tortilla dough, participants needed to calculate precise ingredient ratios. However, to increase mathematical challenge and engagement, EPSTs were not provided with measuring cups, requiring them to apply proportional reasoning and sensory feedback to achieve proper dough consistency. This approach connected abstract mathematical concepts to concrete, culturally relevant experiences (Brown, 2021). EPSTs worked in collaborative teams of 3-4 members (see Figure 1), promoting social learning and peer support. The activity concluded with reflection discussions connecting the mathematical concepts to elementary teaching strategies.

Figure 1: Example of the Process of Making Corn Tortilla by First Mixing the Ingredients, then Using the Tortilla-Maker Machine.

Finch Robots Mathematical Applications

Finch Robots© are educational programmable robots designed specifically for teaching mathematics, computer science, and coding concepts to elementary students. They can also be effectively used with middle and high school students. For this study, the robots were integrated into the mathematics methods course to provide EPSTs with a hands-on technology integration experience. The pedagogical focus was on developing EPSTs' technological pedagogical content knowledge (TPACK) for elementary mathematics. Specific learning activities included programming robots to explore geometric concepts through movement patterns, investigating measurement through distance and angle calculations, and developing spatial reasoning through problem-solving challenges (see figure 2). Based on our implementation experience, Finch Robots provided the crucial connection between mathematical theory and practical application, supporting EPSTs in developing confidence to integrate technology meaningfully into their mathematics instruction while addressing elementary curriculum standards.

Figure 2: EPST Practicing with Finch Robot

Engineering-Based Measurement Tool

This activity engaged EPSTs in constructing a clinometer (see figure 3), an engineering measurement tool used for calculating object heights and determining angles of elevation. The construction and application required EPSTs to apply several mathematics topics including angles, measurements, and distances, while working in small teams. The activity targeted specific elementary mathematics standards related to geometry and measurement. The main reason for exposing the EPSTs to build and use the clinometer was for them to experience firsthand the intersection between mathematics and engineering through applied trigonometry and measurements. In addition, to model how an activity could take place outside the classroom, that can later be used as part of a lesson in the classroom. Although that a clinometer could be used to calculate heights of trees or buildings (or any other object) using any angle, for this particular activity with EPST, only angles of 30º, 45º, and 60º degrees were considered to align with their future grade-level teaching responsibilities (i.e., from first to fifth grade). In figure 6 below, an EPSTs is shown measuring the university library.

For us as teacher educators, focusing on STEM integration, this activity bridges multiple STEM disciplines by combining creativity, teamwork, engineering design principles, geometric understanding, and mathematical application skills. The use of accessible materials demonstrates how abstract mathematical concepts can be transformed into concrete ideas that EPSTs could undoubtedly integrate in their teaching.

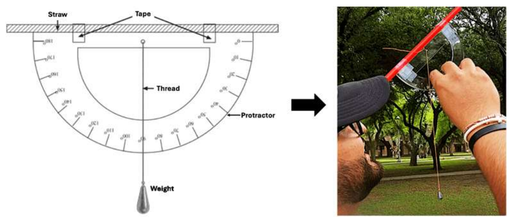

Figure 3: Clinometer description and a EPST using it.

Mixed-Reality Simulations

The EPSTs were exposed to mixed-reality simulations (MRS) to support the development of their mathematical pedagogical skills in the classroom. Studies have found that EPSTs greatly benefit from being exposed to MRS to practice and develop productive mathematical talk moves to orchestrate classroom discourse (Aguilar & Flores, 2022; Aguilar & Telese, 2018; Zhengtao & Hidayat, 2025).

During an MRS session, the EPSTs interact in a Zoom-type session with an avatar that it is controlled by an educational specialist, who have previously been prepared into the simulated scenario to be practiced (see figure 7). In the case of the EPSTs that participated in this study, they were exposed to three different problem-solving mathematical activities that followed a cognitive guide instruction framework developed by Carpenter et al. (1999). Following the exposure, the EPSTs had to write a guided self-reflection essay about their experiences and provide feedback to 3-4 peers. In addition, several EPTS's recorded videos were randomly selected to be discussed in class, as a whole-classroom discussion. The durations of each exposure lasted about 9-15 minutes, which is considered to be similar to an approximately 45 minutes of a real-life setting experience. It is relevant to mention that the exposure to MRS provided the EPSTs an approximation to the practice (Grossman, 2021), that they would not have until their last year of their teacher preparation program, when they are required to participate in clinical teaching practices. This serves as a critical connection between the teacher preparation coursework and field experiences, which allows the EPSTs to start practicing theoretical knowledge in contextual settings while developing confidence in mathematics pedagogies (Aguilar & Flores, 2022).

Figure 4: Example of an EPST Interacting with an Avatar in a Mixed-Reality Session.

Makey-Makey Electrical Circuits

Makey-Makey© is an innovative educational set tool intended to provide a STEM experience related to electrical circuits by using a circuit board. The board use a simple USB cable that connects to a computer. The EPSTs were modeled how to use and integrate Makey-Makey within their future lessons (See figure 5) by exploring how a circuit works in a real setting. The use of Makey-Makey served as a conceptual-experienced between mathematics and STEM by supporting the exploration of circuits, conductivity, and computational thinking, while reinforcing mathematical concepts. The EPSTs could design interactive mathematics games where conductive materials (e.g., like fruit, play-dough, aluminum foil, or pencil granite) could become manipulatives for different topics like measuring, counting, geometric figures, or patterns (see figure 5).

As a hands-on STEM tool, Makey-Makey enabled EPSTs to experience how abstract mathematical concepts could be physically represented through circuits. This supported their preparation by demonstrating how to foster spatial reasoning and pattern recognition while developing technological pedagogical content knowledge. The activities were designed to show how interdisciplinary lessons could naturally integrate mathematics, science, and engineering principles at the elementary level.

Figure 5: EPSTs creating a math related lesson with Makey-Makey.

Data Analysis

Our quantitative analysis included descriptive statistics and paired-samples t-tests to examine pre-post changes. We verified normality using Shapiro-Wilk tests and examined outliers using boxplots. Analysis of covariance (ANCOVA) was conducted controlling for the EPSTs sex, program of study, and prior STEM experience to examine potential moderating effects. Effect sizes were calculated using Cohen's d to determine practical significance of observed changes, with 95% confidence intervals reported for all effect sizes. For the qualitative data, all interviews were transcribed and analyzed using a systematic two-cycle coding process (Saldaña & Omasta, 2016). Initial in-vivo coding captured participants' own language and expressions, followed by pattern coding to identify broader themes. For example, initial codes such as "makes math more fun," "students would be more engaged," and "hands-on is better" were categorized under the broader theme of "enhanced student engagement through experiential learning." Qualitative data coding's inter-rater agreement was established at 88% between two independent coders.

In the end, all the quantitative and qualitative data were integrated during the interpretation phase, which is depicted in the results section below. We used a joint display analysis (Creswell & Plano Clark, 2017), where statistical findings were compared with qualitative themes to identify convergent, divergent, or complementary results.

RESULTS

In this section we are depicting the findings of EPST's attitudes and self-efficacy after been exposed to a series of STEM-related activities during a mathematics methods course. We have divided the section in two parts: The qualitative and the quantitative outcomes.

Quantitative outcomes

In table 1 below we depict the descriptive statistics of the data divided by sex, age, program of study within the teacher preparation program, student's classification (understood as first or non-first generation in college), and the level of experience in STEM.

Characteristics	*n*	%	Total
Sex			
Female	67	89%	75
Male	8	11%	
Age			
19-20	20	26%	75
21-22	32	43%	
23-24	10	13%	
25+	13	17%	
Program of Study			
EC-3 (Early Childhood - 3rd Grade)	9	13%	75

EC-6 (Early Childhood - 6th grade) generalist	13	17%	
Bilingual Education	40	53%	
ESL (English as a Second Language)	7	9%	
Special Education	6	8%	
Student Classification			
First Generation College	48	64%	75
Non-First Generation	27	36%	
STEM Experience			
Minimum (2 courses or less)	8	11%	75
None	67	89%	

Table 1: Demographic Characteristics of Elementary Pre-Service Teachers

From table 1, there are several important aspects that can be highlighted. First, most of the EPTSs participating in this study were females, as identified by their biological sex. This is not surprising since historically there has been more females in teacher preparation programs than males (NCES, 2022; Ingersoll et al., 2021). However, there are mindsets and gaps differences between males and females in terms of STEM. For example, when the EPSTs were first asked about if they find challenging integrating STEM activities within their instruction, 40% of males disagree with this statement, where only 13% of females disagree. In addition, when we asked the EPTSs if they felt confident in integrating STEM in their lessons, about 50% females agree or completely agree, where 63% of males completely agree with this statement. This could be potentially important, since there has been a shortage of females in STEM, mainly in minorities populations (Fry et al., 2021).

We were particularly interested in finding evidence that support our assumption that by exposing the EPSTs to an experiential learning in STEM their confident, interest, and value toward it would develop. Second, most of the EPSTs were in the bilingual program of study and had never taken a course related to STEM. These could potentially impact how the EPSTs responded to the questions in the survey, since they did not have any previous experience with STEM activities. Third, most of the EPSTs that participated in the study have not experience with STEM (89%). This is worrisome, since to develop a STEM mindset in elementary students, teachers need be ready and well prepared in how to integrate STEM ideas within their lessons, which is part we decided to conduct this study.

In regard to the EPTS's responses to the pre- and post-test, we have decided to depict a sample of the characteristics that were measured with the intention of providing a holistic approach of the instrument. To this end, we randomly selected two items in each measured characteristic (See table 2), and then organized the responses for each item (see table 3), depicting a combined responds for answers as "completely agree or agree" and "completely disagree or disagree" for the pre and post survey responses, recalling the survey was a liker-scale from 1 to 5, where 1 represented completely disagree, and 5 completely agree. See appendix B for the complete responses.

Characteristic	ITEM Question
Self-confident and ability	2. I am confident I can integrate STEM/STEM (e.g., robotics) for teaching in elementary.
	6. With my current experience in STEM/STEM, I feel prepared to integrate related concepts and tools (e.g., robotics) within my lesson plans and future teaching.
Value and enjoyment of STEM	7. Children should learn STEM/STEM related concepts (e.g., Robotics) in Elementary.
	10.Students would conceptually learn mathematics if STEM/STEM related concepts (e.g., Robotics) are used for teaching elementary mathematics.
Performance and effort Expectancy	13. Using STEM/STEM (e.g., robotics) in teaching and learning elementary mathematics would help me to accomplish my teaching goals quickly.
	15. If I use STEM/STEM (e.g., robotics) in teaching and learning elementary mathematics, I will increase my chances of getting a raise once I get a teaching position.
Effort Expectancy	17. My interaction with STEM/STEM related tools like robotics would be easy for me to become skillful at using it.
	18. Integrating STEM/STEM related tools like robotics in my elementary mathematics lessons would be easy for me.
Social Influence and Behavioral Intention	21. If my future colleagues integrate STEM/STEM related tools like robotics within their lesson, I will probably use it in my teaching and learning of elementary mathematics too.
	22. I would use STEM/STEM related tools like robotics in my teaching and learning once I become a teacher.

Table 2: Sample of Questions by Measured Characteristic

From table 3 below, it can be noticed that in every item the EPST's responses positively increased from the pre to the post implementation. It is important to mention that this does not means they are all statistically significant. To find evidence of this we have conducted a t-test and a covariance analysis. However, some inferences emerged from the raw data. For example, item 2, 6 & 17 shows that EPST's confidence to integrate some STEM ideas in their lessons, improved. This is relevant since, the ETPS's mindset toward STEM has positively shifted. In addition, in items 7, 10 & 22, the EPSTs depicted comprehension about the importance of engaging elementary students in STEM activities to support and promote conceptual understandings beyond simple lectures, same as the EPSTs were exposed in an experiential learning approach (Kolb & Kolb, 2009).

#	Pre		Post	
	Agree or Completely Agree	Disagree or completely disagree	Agree or Completely Agree	Disagree or completely disagree
2	60%	11%	74%	6%
6	21%	42%	72%	2%
7	81%	0%	91%	2%
10	53%	6%	79%	0%
13	53%	2%	85%	2%
15	40%	0%	70%	4%

17	47%	17%	70%	0%
18	34%	15%	64%	2%
21	75%	0%	87%	0%
22	79%	2%	85%	0%

Table 3: Raw Data of Selected Survey Items

Also, items 17, 18 & 22 showed the EPSTs see the use and integration of STEM activities as something that would help them to better perform in their future teacher responsibilities and to achieve their teaching goals. This is relevant because the EPTS depicted to be inclined to accept the presented STEM ideas as new ways of approaching their own future pedagogies (Abbad, 2021).

Elementary Pre-service Teacher that participated in the study, were barely exposed and engaged to any structured STEM activity during their teacher preparation program. We decided to change this, because as researchers, we recognize that for young elementary scholars to develop a STEM mindset, they need to be exposed to it since a very young age, rather than later when they get to middle or high school. We understand that there are many more relevant aspects that need to be said and shared. These are shared in the next paragraph.

Continuing with our analysis of the quantitative data, we conducted a pair t-test analysis of the pre and post data by creating the mean scores for each construct and observing and comparing the differences between the pre and post responses. In table 4 below we depict the means of the EPST's responses and its standard deviation for each of the measured construct.

Measured Construct	**Pre (*SD*)**	**Post (*SD*)**	**p-value, effect size [95% CI]**
Self-confidence and ability	3.34 (0.39)	3.54 (0.51)	$p < 0.01$, $d = 0.33$ [0.20, 0.46]
Value and Enjoyment of STEM	3.70 (0.44)	4.00 (0.51)	$p < 0.01$, $d = 0.43$ [0.29, 0.57]
Performance expectancy	3.70 (0.59)	4.09 (0.58)	$p < 0.01$, $d = 0.53$ [0.38, 0.68]
Effort Expectancy	3.30 (0.75)	3.98 (0.74)	$p < 0.01$, $d = 0.64$ [0.48, 0.80]
Social influence	3.89 (0.69)	4.21 (0.66)	$p < 0.01$, $d = 0.33$ [0.19, 0.47]
Behavioral intention	3.60 (0.75)	4.18 (0.71)	$p < 0.01$, $d = 0.59$ [0.43, 0.75]

Table 4: Mean Responses and the Standard Deviation from the Survey

The paired sample t-test revealed that the EPSTs showed significantly higher responses in all the constructs after the implementation (see Table 4). All six measured constructs depict statistically significant improvements from pre to post measurements ($p < 0.01$). This consistent pattern indicates that the intervention had a meaningful impact across all measured areas. Effect sizes ranged from small to medium-large, indicating both statistical and practical significance. The largest effect sizes were observed for Effort Expectancy ($d = 0.64$) and Behavioral Intention ($d = 0.59$), suggesting that the experiential learning intervention was particularly effective in reducing perceived implementation difficulty and increasing intentions to use STEM approaches in future teaching. These findings align with technology acceptance theory predictions that effort expectancy and behavioral intention are primary determinants of adoption (Venkatesh et al., 2003).

Then, we subdivided participants (i.e., the EPSTs) based on their status (i.e., first generation), sex, program of study, and background knowledge in STEM, and compared the groups' post-survey responses with pre-survey as a covariate on each construct. In regard to the status of the EPSTs (i.e., first-generation versus non-first-generation), we found that there was no difference between the subgroups in all the constructs (see Table 5), where first-generation group showed higher responses than non-first generation after the implementation. This is relevant, since being a first-generation student, does not reflect to be a factor influencing the EPTSs mindset toward STEM.

Measured Construct	**First generation (n = 49)**	**Non-First generation (n = 26)**	**p-value**
Self-confidence and ability	3.54 (0.52)	3.54 (0.51)	p = 0.41
Value and Enjoyment of STEM	4.02 (0.51)	3.94 (0.52)	p = 0.53
Performance expectancy	4.13 (0.59)	4.03 (0.58)	p = 0.20
Effort Expectancy	4.07 (0.72)	3.80 (0.76)	p = 0.31
Social influence	4.27 (0.67)	4.12 (0.65)	p = 0.45
Behavioral intention	4.27 (0.65)	4.01 (0.80)	p = 0.49

Table 5: Mean Scores Comparison Between First-Generation and Non-First-Generation Groups in Post-Survey Responses with Pre-Survey as a Covariate

We also conducted a covariance analysis considering the EPST's previous experiences with STEM, for which most of them (*n*=71) mentioned not having any previous experience with STEM activities implementation or exposure. We did not find any evidence that the EPST's STEM mindset was different between the subgroups, which means that having or not experience with STEM has an impact on the EPST's minded toward it. In a similar pattern, we also analyzed the differences based on sex and the program of study of the EPSTs. (See tables 6 and 7 below).

	Male (n = 8)	**Female** (n = 67)	**p-value**
Self-confidence and ability	3.54 (0.24)	3.54 (0.54)	p = 0.86
Value and Enjoyment of STEM	3.98 (0.39)	4.00 (0.53)	p = 0.93
Performance expectancy	4.28 (0.49)	4.07 (0.59)	p = 0.36
Effort Expectancy	4.18 (0.96)	3.95 (0.72)	p = 0.43
Social influence	4.13 (0.99)	4.22 (0.62)	p = 0.68
Behavioral intention	3.88 (1.31)	4.22 (0.61)	p = 0.21

Table 6: Mean Score Comparison of Sex In Post-Survey with Pre-Survey as a Covariate

Based on the EPST's sex—i.e., male (*n*=8) and female (*n*=67) —the covariation analysis depicted above in Table 6 shows that there were no statistically significant differences between males and females on any of the measured constructs. However, this was one our biggest limitation, since the nature of the sample had this composition —i.e., the EPTSs that participated in the study. In terms of means and variability, we did notice that for the behavioral intention construct, it shows the largest mean difference between groups, with females scoring higher (4.22) than males (3.88). The high standard deviation for males (1.31) indicates considerable variation within this small group.

	Bilingual (40)	ESL (7)	Spe. Ed (6)	EC6 (13)	Early Ed (9)	p-value
Self-confidence and ability	3.56 (0.57)	3.32 (0.21)	3.57 (0.32)	3.44 (0.28)	3.62 (0.59)	p = 0.85
Value and Enjoyment of STEM	4.04 (0.53)	3.73 (0.72)	4.06 (0.38)	3.89 (0.35)	4.00 (0.59)	p = 0.85
Performance expectancy	4.17 (0.61)	3.95 (0.87)	3.97 (0.36)	3.89 (0.45)	4.25 (0.45)	p = 0.62
Effort Expectancy	4.06 (0.73)	3.96 (0.74)	4.02 (0.69)	3.69 (0.76)	3.87 (0.97)	p = 0.81
Social influence	4.31 (0.64)	4.00 (0.71)	4.22 (0.67)	4.00 (0.71)	4.17 (0.75)	p = 0.76
Behavioral intention	4.23 (0.72)	4.20 (0.69)	4.06 (1.02)	4.08 (0.48)	4.13 (0.72)	p = 0.97

Table 7: Mean Score Comparison Of Program of Study in Post-Survey with Pre-Survey as a Covariate

The covariance analysis of the EPSTs based on their program of study depicted in table 7, shows that there were not no statistically significant differences, since all p-values are above 0.05 (ranging from 0.62 to 0.97), on all of the measured constructs. Similarly to the analysis conducted considering the EPST's sex, the distribution of the sample played an important role, however, once again this is an uncontrollable variable, since all EPSTs are required to take the mathematics methods course regardless of their program of study. Despite the above, our analysis shows that the bilingual education EPSTs scored higher on the constructs related to performance expectancy (4.17) and social influence (4.31), the ESL EPSTs scored the lowest across most constructs compared to other groups, and special education EPSTs show relatively higher scores on value and enjoyment of STEM construct (4.06). In terms of the behavioral intention construct, all EPST's groups depicted a consistency scored (p= .97), suggesting that it is likely the program of study was not relevant in terms of their behavioral intentions.

In general, throughout our analysis we found evidence that support our claim that the implementation of STEM activities with EPSTs effectively improved their perceptions, attitudes, and behavioral intentions related to STEM education and integration at the elementary level, with particularly strong impacts on effort expectations and intended future engagement. In addition, we found evidence that all the variables considered in the covariance analysis (i.e., sex, program of study, or ETPS's status) had an impact on their attitudes and self-efficacy toward the use, implementation, and integration of STEM relegated activities within their future lessons with elementary students.

Qualitative Outcomes

As mentioned above, we decided to conduct interviews with a subset of EPSTs that volunteered for this purpose. In total, 8 EPSTs participated in semi-structured open-ended interviews (Zhang & Wildemuth, 2009) that were video recorded. Each interview lasted approximately 20-30 minutes. The EPSTs were asked 9 questions (See table 8) related to their experiential learning experience during the math methods, where they were exposed to several STEM-related activities as described above.

1. Do you consider that (STEM Teaching) should start earlier (e.g., elementary?)? Why?
2. Can you talk about any subject in elementary that can be taught using robotics/STEM?
3. Do you think robotics/STEM activities during the course were and will be helpful to you?
4. Please explain how using robotics/STEM can enhance mathematics learning and teaching.
5. How was your experience (or how would be your experience) creating a lesson plan that integrates the use of robotics/STEM to teach mathematics in elementary (if you did one)?
6. Did you (or your group) go above and beyond the class requirements about robotics/STEM?
7. Did you enjoy (or would enjoy) using robotics/STEM to create a lesson plan? Please explain your rationale.
8. Would you like to integrate robotics/STEM into your instruction once you become an elementary teacher?
9. What did you dislike about robotics/STEM activities during the course?

Table 8: Interview Questions

Once all the interviews were transcribed, we conducted an open-coding double-round (Saldaña, 2014) analysis to find the most common patterns, ideas, and opinions from the EPTSs responses. After discussing our findings, we obtained a final inter-rating agreement (Cole, 2024) of 88% for each of the pattern found in each question. In the following paragraphs we depict the thematic patterns we found, for which data revealed four major themes that shows the EPSTs' experiences and perspectives following the STEM activities integration:

Theme 1: Changes in STEM Perceptions

Participants consistently described a fundamental shift in how they viewed STEM education's role in elementary classrooms. Initially, many EPSTs perceived STEM as content too advanced or complex for young learners. Following the implementation of the activities, EPSTs reconceptualized STEM as a pedagogical approach that could enhance existing mathematics and science instruction rather than additional content to cover. EPSTs quotes include: "I used to think STEM was just for older kids, like middle school or high school, but now I see how it can make elementary math come alive and actually help kids understand better.", "Before this class, I thought STEM meant complicated engineering projects, but now I understand it's about connecting subjects in ways that make sense to kids." This theme aligns with research indicating that teacher beliefs about developmental appropriateness significantly influence instructional decisions (Stipek & Byler, 1997). The shift from viewing STEM as "too advanced" to "developmentally appropriate and beneficial" represents a crucial shift for future elementary STEM implementation.

Theme 2: Enhanced Pedagogical Confidence

EPSTs reported substantial increases in confidence regarding their ability to implement hands-on, integrated learning experiences. This finding directly supports Bandura's (1997) self-efficacy theory, as participants gained mastery experiences through successful completion of STEM activities, leading to increased self-efficacy beliefs. Key expressions of enhanced confidence included: "I feel so much more prepared now to actually try these activities with my students. Before, I would have been terrified, but now I'm excited.", "The hands-on experience made me realize I can do this. It's not as scary as I thought it would be.", "I have actual examples now of what STEM looks like, so I feel ready to adapt and create my own activities." Participants frequently mentioned feeling "more prepared," "excited to try," and "confident" about implementing STEM approaches. This confidence growth is particularly significant given that 89% of participants had no prior STEM experience.

Theme 3: Recognition of Student Engagement Benefits

All interviewed EPSTs recognized STEM activities' potential to increase student engagement and conceptual understanding. They described anticipating higher levels of student motivation, deeper learning, and improved mathematical reasoning when STEM approaches are implemented effectively. Example of EPSTs responses include: "Students would be so much more engaged than just sitting and listening to me explaining fractions…when they're building and creating, they're really learning.", "I can see how this makes abstract math concepts concrete. Kids can actually see and touch what they're learning about.", "The hands-on approach helps different types of learners. Not everyone learns by just hearing about it." This theme demonstrates EPSTs' developing pedagogical content knowledge and understanding of how experiential learning can support diverse learning needs and styles.

Theme 4: Implementation Concerns and Realistic Planning

Despite increased enthusiasm, EPSTs expressed realistic concerns about implementation challenges, including time constraints, resource availability, classroom management with hands-on activities, and curricular pressures. Importantly, these concerns were accompanied by problem-solving mindsets and willingness to adapt activities to available resources. Common concerns included: "I worry about having enough materials for all students, but I think I could modify activities to work with what's available.", "Time is always an issue with all the testing requirements, but maybe I could integrate these into existing math lessons.", "Classroom management might be challenging with hands-on activities, but I think the engagement would actually help with behavior." This theme reflects realistic thinking about implementation challenges while maintaining commitment to STEM integration. The presence of both enthusiasm and realistic concern-solving suggests that EPSTs developed a practical perspectives on STEM implementation.

Integration of Qualitative and Quantitative Findings

The qualitative themes that emerged from the interviews strongly converge with the quantitative results obtained, providing triangulation support for the effectiveness of the implementation of the STEM activities with the EPSTs in the following ways. First, the transformation of STEM integration and implementation perceptions aligns with increased value and enjoyment scores. Second, we noticed that confidence was enhanced, which correspond with improved self-efficacy measures. Third, the EPSTs recognized the benefits for their future students. This relates to higher performance expectancy, and last but not less relevant, the realistic implementation planning, which connects with improved effort expectancy and behavioral intentions. These last aspects are relevant since depicts the intention of the EPSTs for adopting and integrating STEM activities in their classroom.

DISCUSSION AND CONCLUSIONS

Our study provides evidence that experiential learning approaches can effectively transform EPST's attitudes, self-efficacy, and behavioral intentions toward STEM integration. The consistent pattern of statistically significant improvements across all measured constructs ($d = 0.33$ to 0.64), combined with qualitative evidence of improved perspectives and enhanced confidence, suggests that structured hands-on experiential STEM activities address fundamental barriers to elementary STEM implementation. We aimed to contribute new knowledge to the field by depicting evidence that structured experiential learning integration can develop STEM acceptance and self-efficacy among EPSTs who typically have limited STEM backgrounds. Unlike previous research that has focused primarily on content knowledge development (e.g., Nadelson et al., 2013), our study reveals that acceptance-based approaches targeting performance expectations, effort expectations, and behavioral intentions may be effective for developing the confident EPSTs. In fact, the particularly strong effects we observed for effort expectancy ($d = 0.64$) and behavioral intention ($d = 0.59$) align with Venkatesh et al.'s (2003) findings that these constructs are primary determinants of technology adoption and use. In the context of STEM education, these results suggest that reducing perceived implementation difficulty while enhancing performance expectations can significantly increase the likelihood of future STEM integration.

Our findings extend previous research by Bursal and Paznokas (2006) and Tomas et al. (2019), who found that hands-on experiences improve pre-service teachers' STEM confidence. We advance the field by providing evidence through which experiential learning influences STEM adoption intentions, bridging self-efficacy theory with technology acceptance models in teacher education contexts.

Implications for Mathematics Teacher Education Practice

The enhancement of EPSTs' perspectives on the developmental appropriateness of elementary STEM education represents a significant contribution to addressing gaps in early STEM exposure. EPSTs can develop both competence and confidence through structured experiences. Our study provided evidence for systematic approaches to improving elementary STEM education quality. Specifically, teacher preparation programs could integrate experiential STEM activities into required methods courses where natural connections exist between manipulative use and STEM integration, prioritizing self-efficacy development (Bandura, 1997) through successful hands-on STEM implementation, rather than theoretical coursework alone. Also incorporating culturally relevant activities to connect mathematical concepts to students' cultural backgrounds. Based on our findings, we recommend that mathematics teacher educators consider a structured lesson incorporating Kolb's (1984) experiential learning cycle, beginning with concrete experiences—such as constructing measurement tools or programming educational robots—followed by reflective observation, abstract conceptualization through explicit connections to elementary mathematics standards, and active experimentation as EPSTs adapt activities for their future classrooms.

Teacher educators could allocate about 90 min./activity, with 30 min. for hands-on engagement, 20 min. for guided reflection connecting mathematical concepts to STEM integration, 25 min. for collaborative discussion of implementation strategies, and 15 min. for individual planning of classroom adaptations, with timing adjusted according to course needs. The lesson design should emphasize culturally relevant contexts while addressing mathematics anxiety through successful mastery experiences (Bandura, 1997), as our results indicated these factors significantly contributed to increased confidence and value perceptions. We recommend that teacher educators model the pedagogical approaches they want EPSTs to adopt—including explicit verbalization of mathematical thinking, demonstration of how abstract concepts connect to real-world applications, and facilitation of collaborative problem-solving that mirrors effective elementary classroom practice. Pre- and post-lesson assessments using adapted versions of our self-efficacy and behavioral intention measures can help teacher educators document growth and adjust instruction accordingly. Our goal in recommending this empirically grounded lesson design is to provide a practical framework for transforming traditional mathematics methods courses into experiential learning environments that develop EPSTs who are both confident and competent in STEM integration at the elementary level.

Limitations and Future Research

We acknowledge several limitations in our study. The relatively small sample size (N = 75) evident sex imbalance (89% female), and single-institution design further limit generalizability, though the Hispanic-Serving Institution context provides valuable insights for similar settings. Additionally, our focus on immediate post-intervention effects precludes conclusions about long-term retention of attitudes and behavioral changes, self-report measures introduce potential social desirability bias, and EPSTs' actual future classroom implementation remains unobserved. The study's placement within a required mathematics methods course may also have influenced participants' responses and engagement. Future research should address these limitations through randomized controlled designs to establish causality, longitudinal follow-up tracking attitude and behavior persistence as EPSTs transition into classroom teaching, direct observation of STEM implementation, and expanded samples with greater sex diversity—directions we are actively pursuing as next steps. Notwithstanding these limitations, our study provides meaningful empirical evidence that experiential learning approaches within teacher preparation programs can effectively enhance elementary pre-service teachers' attitudes, self-efficacy, and intentions toward STEM integration, supporting broader efforts to ensure all students—particularly those in underserved communities—have access to high-quality, interdisciplinary STEM education from their earliest school years.

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APPENDIX A

Demographic component
Age
Sex
Are you first-generation College student?
Program Specialization - Selected Choice
Have you taken any STEM course (e.g., Computer Science, Biology, engineering) in College?
Do you have any STEM experience?

Self-confident and ability
Learning how to integrate STEM (e.g., robotics) in teaching elementary mathematics sound challenging.
I am confident I can integrate STEM (e.g., robotics) for teaching in elementary.
I feel at ease using STEM resources (e.g., like robots) to teach in elementary.
I would hesitate in integrating STEM (e.g., Robotics) in my teaching for fear of making mistakes I won't be able to correct.
I am unsure of my ability to integrate STEM (e.g., Robotics) in my teaching.
With my current experience in STEM, I feel prepared to integrate related concepts and tools (e.g., robotics) within my lesson plans and future teaching.

Value and enjoyment of STEAM
Children should learn STEM related concepts (e.g., Robotics) in Elementary.
Integrating STEM related concepts (e.g., Robotics) in elementary teaching would be enjoyable and stimulating for me.
Students would have hard time learning mathematics if STEM related concepts (e.g., Robotics) are integrated in a lesson.
Students would conceptually learn mathematics if STEM related concepts (e.g., Robotics) are used for teaching elementary mathematics.
I expect my future students to enjoy learning elementary mathematics through the use and implementation of STEM resources like robotics.

Performance Expectancy
The use of STEM (e.g., robotics) in elementary to teach and learn mathematics is useful.
Using STEM (e.g., robotics) in teaching and learning elementary mathematics would help me to accomplish my teaching goals quickly.

Using STEM (e.g., robotics) in teaching and learning in elementary mathematics could increases my productivity.
If I use STEM (e.g., robotics) in teaching and learning elementary mathematics, I will increase my chances of getting a raise once I get a teaching position.

Effort Expectancy
My interaction with STEM related tools like robotics in teaching and learning would be clear and understandable for me.
My interaction with STEM related tools like robotics would be easy for me to become skillful at using it.
Integrating STEM related tools like robotics in my elementary mathematics lessons would be easy for me.
Learning how to use STEM related tools like robotics would be easy for me.
Learning how to operate and program STEM related tools like robotics would be easy for me.

Social Influence and Behavioral Intention
If my future colleagues integrate STEM related tools like robotics within their lesson, I will probably use it in my teaching and learning of elementary mathematics too.
I would use STEM related tools like robotics in my teaching and learning once I become a teacher.

Raking scale (1-10)
How likely is that you will seek ways to integrate STEM related ideas like the use of Robotics (or any other) in your elementary teaching once you start your teaching career? (1 not likely at all - 10 Very possible).

APPENDIX B

ITEM	Pre (%)		Post (%)	
	Agree or Completely Agree	Disagree or comple-tely disa-gree	Agree or Completely Agree	Disagree or comple-tely disa-gree
Learning how to integrate STEM (e.g., robotics) in teaching elementary mathematics sound challenging.	57%	15%	55%	28%
I am confident I can integrate STEM (e.g., robotics) for teaching in elementary.	60%	11%	74%	6%
I feel at ease using STEM resources (e.g., like robots) to teach in elementary.	32%	28%	64%	4%

I would hesitate in integrating STEM (e.g., Robotics) in my teaching for fear of making mistakes I won't be able to correct.	57%	19%	26%	51%
I am unsure of my ability to integrate STEM (e.g., Robotics, engineering) in my teaching.	58%	15%	25%	47%
With my current experience in STEM, I feel prepared to integrate related concepts and tools (e.g., robotics) within my lesson plans and future teaching.	21%	42%	72%	2%
Children should learn STEM related concepts (e.g., Robotics) in Elementary.	81%	0%	91%	2%
Integrating STEM related concepts (e.g., Robotics) in elementary teaching would be enjoyable and stimulating for me.	64%	6%	85%	6%
Students would have hard time learning mathematics if STEM related concepts (e.g., Robotics) are integrated in a lesson.	19%	42%	15%	57%
Students would conceptually learn mathematics if STEM related concepts (e.g., Robotics) are used for teaching elementary mathematics.	53%	6%	79%	0%
I expect my future students to enjoy learning elementary mathematics through the use and implementation of STEM resources like robotics.	64%	0%	91%	0%
The use of STEM (e.g., robotics) in elementary to teach and learn mathematics is useful.	77%	0%	92%	0%
Using STEM (e.g., robotics) in teaching and learning elementary mathematics would help me to accomplish my teaching goals quickly.	53%	2%	85%	2%
Using STEM (e.g., robotics) in teaching and learning in elementary mathematics could increases my productivity.	66%	2%	83%	2%
If I use STEM (e.g., robotics) in teaching and learning elementary mathematics, I will increase my chances of getting a raise once I get a teaching position.	40%	0%	70%	4%
My interaction with STEM related tools like robotics in teaching and learning would be clear and understandable for me.	42%	23%	79%	0%
My interaction with STEM related tools like robotics would be easy for me to become skillful at using it.	47%	17%	70%	0%

Integrating STEM related tools like robotics in my elementary mathematics lessons would be easy for me.	34%	15%	64%	2%
Learning how to use STEM related tools like robotics would be easy for me.	38%	17%	62%	4%
Learning how to operate and program STEM related tools like robotics would be easy for me.	34%	17%	70%	4%
If my future colleagues integrate STEM related tools like robotics within their lesson, I will probably use it in my teaching and learning of elementary mathematics too.	75%	0%	87%	0%
I would use STEM related tools like robotics in my teaching and learning once I become a teacher.	79%	2%	85%	0%
How likely is that you will seek ways to integrate STEM related ideas like the use of Robotics (or any other) in your elementary teaching once you start your teaching career? (1 not likely at all - 10 Very possible)	6.5		8.5	