

Article

Coding Robots for Empathy: Teacher Candidates Learning to Teach STEAM Integration in Communities of Practice

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Abstract

Despite growing curricular emphasis on computational thinking (CT) and engineering design practice (EDP), preparing elementary teacher candidates (ETCs) for integrated, practice-based instruction remains challenging. Grounded in Communities of Practice (CoP) and design-based implementation research (DBIR) frameworks, this study examines how ETCs (pre-survey: $n = 23$, post-survey: $n = 13$) develop learning-to-teach practices for integrating coding and robotics into PreK–5 STEAM learning (STEM with Arts integration) to foster these competencies. The study is situated within an interdisciplinary, community-partnered course, *Toying with Technology (TwT)*, where ETCs collaborate in Critical Friends teams to design, facilitate, and reflect on community partners' need-oriented, empathy-centered STEAM experiences. Utilizing PreK–5 learning technologies and field-based insights from STEM/STEAM professionals, ETCs developed 5E lesson plans integrating science, literacy, mathematics, and robotics, culminating in both an in-person and a virtual STEAM Family Night. Data sources include pre- and post-surveys measuring ETCs' technology integration perceptions, post-field exit tickets, family feedback, community partner reflections, and course artifacts. Pre-survey results indicated limited prior experience and neutral confidence regarding technology integration. In contrast, post-survey findings demonstrated significant increases in self-reported confidence, conceptual understanding of CT and EDP, and readiness to facilitate empathy-centered, technology-rich learning. Qualitative analysis further revealed growth in collaboration, problem-solving, and pedagogical reasoning, while parent and partner feedback highlighted high levels of engagement and increased STEAM interest. Overall, this study provides initial empirical evidence, within a community-partnered, empathy-oriented course design, showing how community-engaged teacher education, informed by CoP and DBIR frameworks, prepares ETCs to teach CT, EDP, and critical problem-solving through integrated, authentic STEAM integration.



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1. Introduction

Problem-solving skills are crucial for 21st-century society and the workforce, reflecting one's ability to identify optimal solutions to ill-defined problems (Bariyyah, 2021; Mourtos et al., 2004). Computational Thinking (CT) is closely linked to problem-solving (Wu et al., 2024) as a transferable intellectual tool for everyone (Wing, 2008), comprising four major components: problem decomposition, pattern recognition, abstraction, and algorithms (Williams, 2021; Wu et al., 2024). CT is honed through practices of analyzing and explaining real-world complex problems and developing computing solutions (Denning & Tedre, 2019). Especially for K-5 children, CT can be fostered through coding experiences with web-based coding and programming platforms and physical robot-based coding tools (Williams, 2021). Although coding-integrated curricula effectively enhance students' CT and motivation, a lack of teacher training remains a key pedagogical constraint. This gap highlights the need for targeted professional development to build teachers' competence and confidence in delivering integrated instruction (Mills et al., 2025).

Elementary teacher candidates (ETCs) must be prepared to integrate CT into K-5 classrooms. This preparation is essential not only because CT fosters vital 21st-century skills like problem-solving, systematic reasoning, and creativity (Falloon, 2024), but also because it provides a foundation for human-centered curricula. Through this approach, learners tackle authentic problems using empathy—defined here as understanding users' experiences, needs, and perspectives to design sustainable engineering solutions (Shim, 2025; Williams, 2021). Furthermore, this model aligns with Communities of Practice (CoP) principles by emphasizing social learning and active participation in shared practices (Wenger, 2000).

Equally important is the engineering design practice outlined in the Next Generation Science Standards (NGSS), which emphasizes engaging learners in defining problems, designing solutions, and applying scientific and engineering knowledge to address real-world challenges (NGSS Lead States, 2013). The engineering design practice (EDP) is a systematic approach to obtaining formulated solutions by identifying and defining problems, generating alternative solutions, evaluating them, selecting a solution, and improving it (Kosky & Keat, 2020). EDP is not necessarily linear but rather iterative (Linh & Huong, 2021). EDP also supports empathy-based, human-centered engagement in learning because it concerns for human needs (Deng et al., 2026) and involves both mind-on and hands-on activities (Abdurrahman et al., 2023).

ETCs need to be prepared to teach EDP because it is closely related to problem-solving, creativity, empathy, and collaboration (Deng et al., 2026), and introduces students to technical fields (Linh & Huong, 2021). NGSS emphasize integrating EDP into K-12 science education through project-based learning, enabling students to solve real-world problems by connecting multiple disciplines (NGSS Lead States, 2013).

An existing study on engineering education from a cognitive perspective finds that engineering problem-solving is closely linked to spatial ability, which is essential for processing and visualizing unfamiliar, non-routine tasks (Duffy et al., 2024). Just as the EDP requires identifying and defining problems before formulating testable solutions (Kosky & Keat, 2020), the cognitive term problem representation is recognized as a crucial phase that must precede any solution path in engineering education research (Duffy et al., 2024). Spatial ability is trainable through learning technology-based practices by visualizing thinking. Sketching practices integrated with multimedia learning software have proven effective in enhancing the 3D spatial abilities of adolescents and college students, providing pedagogical implications for using learning technology to make mental representation visible in engineering education for nonroutine problem-solving (S. A. Sorby, 2019). However, despite the importance of spatial skills in engineering and other STEM fields, current

PreK–12 curricula often lack explicit instruction to prepare students for success at the collegiate level (S. Sorby et al., 2026).

Empathy is considered crucial to engineering design because it begins with understanding users' needs and contexts (Shim, 2025). Real-world examples show how students work with teachers or community partners to build solutions to improve human and environmental conditions (Williams, 2021). For instance, elementary teachers and students used mapping, coding, systems thinking, and storytelling to design an augmented-reality walking tour to provide an interactive way to share community stories and culture (ARIS Community Walking Tours). As a global collaborative project, students across the world used decomposition and algorithms to build accessible coding lessons and activities for schools worldwide (Code.org/Hour of Code Movement). In addition, students teamed up with community innovators to design apps using NASA open data to address environmental and societal challenges, employing skills such as data analysis, coding, modeling, and systems thinking (NASA Apps Challenge). These community-based, empathy-centered projects aim to meet the community's authentic needs by having students use knowledge and skills of CT, EDP, science, and technology.

Empathy is also emphasized in inclusive science, technology, engineering and mathematics (STEM) education, such as in a multicultural STEM framework that addresses the relevance, need and challenge of designing culturally empathetic STEM education (Shim, 2025). Empathy is also found to be used either as a tool to facilitate design-based problem-solving or as an aim to achieve transformative outcomes in STEM education (Han et al., 2026). While more studies examine empathy in inclusive curricula, STEM education, and teacher wellbeing, there is a lack of literature on ETCs' learning experiences with empathy-centered, maker-based STEAM (STEM with arts) through teacher preparation programs (TPPs).

One strategy for integrating relevance and empathy into the TPP is to collaborate with educational communities, allowing learners to address authentic needs and challenges identified by community members. Community-based learning experiences offered by TPPs are found to be effective in enhancing STEM teacher candidates' competence in identifying real needs, critical analysis, solution creation and implementation, and collaborative skills (Dankunprasert et al., 2025; Nava & Park, 2021). Furthermore, community-based training is effective in enhancing science teacher candidates' creative thinking skills, such as originality, risk-taking, elaboration, curiosity, imagination, and flexibility (Widyastuti et al., 2026). On the contrary, a study on co-designing and implementing a community-based engineering-enriched science unit found that the unit failed to enhance most participating teacher candidates' efficacy in teaching similar activities due to limited implementation time (1 or 2 lessons) allocated by the partnered middle school for teacher candidates to carry out their original plans fully; therefore, a longer-term implementation is suggested by the authors (Topçu & Çiftçi, 2023). More studies on community-based, empathy-centered STEM or STEAM TPP curricula to foster 21st-century skills, including CT, EDP, creativity, and collaboration, are needed.

TPP-based interdisciplinary, technological interventions have been shown to increase PreK–5 teacher candidates' positive attitudes toward and efficacy in using educational technology, such as robots, for STEAM learning and teaching. In one study, preschool teacher candidates showed higher acceptance and self-efficacy for using robots in their future classrooms after being introduced to the CT concept and participating in scaffolded programming, debugging tasks, and environment-protective, interdisciplinary projects with educational robots, through two weeks of in-person meetings and one week of asynchronous work (Schina et al., 2021). For improvement, Schina et al. suggest a longer training period and more enriched resources. In another study, ETCs' confidence and

positive perception of using robots to teach STEM were enhanced after interacting with a robotic board that enabled multiple programming solutions to learn about the water cycle through computational thinking, collaboration, and self-directed learning (Hoz et al., 2024).

Approaching CT and EDP from a social learning perspective requires robust empirical investigation. Specifically, more research needs to focus on integrating CT and EDP coding activities into TPP curricula with an emphasis on community context and an empathy orientation. This study examines a semester-long course featuring technology-enhanced, community-based learning in which ETCs address the empathy-centered, authentic needs of partner communities. Such empirical evidence is vital to designing structured interventions that prepare ETCs for next-generation STEM/STEAM education. Overall, this approach has the potential to shape ETCs' CT and EDP competencies, technological literacy, and professional educator identities.

1.1. Research Questions

This study uses a parallel mixed-methods research (MMR) (Teddlie & Tashakkori, 2010) approach to address the following three research questions:

RQ1. How did ETCs perceive their CT and EDP confidence and competence, technological literacy development, and STEM/STEAM educator identity formation in an interdisciplinary, project-based, and community-partnered course, Toy with Technology (TwT), in a TPP in a higher education research institution in the Midwest, United States?

RQ2. What were ETCs' experiences with the empathy-centered and community-based activities in this course?

RQ3. How did those experiences relate to the learning outcomes of TwT?

1.2. Significance of This Study

This study adopts Magana's (2022) engineering education taxonomy as a multi-layered framework, deploying distinct frameworks to address specific project dimensions. Grounded in Design-Based Implementation Research (DBIR), the project applies a Communities of Practice (CoP) lens to examine teacher preparation program (TPP) innovation and equip elementary teacher candidates (ETCs) for 21st-century STEAM instruction. Methodologically, we follow Raju et al. (2024) by utilizing a mixed-methods research (MMR) design to examine how program factors shape students' post-program attitudes. Specifically, this study contributes to the existing literature by examining how ETCs perceive their development of CT and EDP understanding and technology-integration confidence across a semester-long, community-partnered teacher preparation course. It further provides evidence of how Critical Friends, interactions with STEM professionals and STEAM community partners, and authentic teaching with children and families contribute to ETCs' sense-making of CT and EDP and emerging STEM/STEAM educator identities.

2. Toy with Technology Context

Toy with Technology (TwT) is an interdisciplinary TPP course that features project-based, hands-on practice with up-to-date technological platforms and multiple partnerships with STEM/STEAM professionals. Specifically, TwT collaborated with outside program partners, including the informal public education coordinator at the Botanic Garden affiliated with the university, the nonprofit Aspire Afterschool Technological Learning Center (AATLC) principal, and lab engineers and scientists on robotics, virtual reality, and 3D printing, to brainstorm ideas and explore the varying STEM/STEAM educational opportunities and endeavors. There are three major goals associated with this course: (1) examine and analyze current STEM and technology trends to understand how scientists and engineers design solutions in real-world contexts; (2) identify and integrate learning technologies into

various PK–12 STEM educational settings by addressing learner needs and emphasizing CT and EDP; and (3) design and implement innovative, hands-on STEAM experiences that integrate technology to promote creativity, critical thinking, collaboration, and problem-solving. These objectives align with NGSS science and engineering practices.

The course structure follows the 5E Learning Cycle Model (Bybee & Landes, 1990; Duran & Duran, 2004) with a Critical Friends routine—trusted peers who provide critical and constructive feedback (Storey & Richard, 2015) to foster ETCs’ technological literacy for 21st-century STEM/STEAM learning and instruction. 5E Learning Cycle emphasizes learner-centeredness and “doing first” across the 5E (Engage, Explore, Explain, Elaborate, and Evaluate) components to encourage inquiry-based learning in science and interdisciplinary classrooms (Bybee & Landes, 1990; Duran & Duran, 2004). Moreover, this course adopts a community-oriented, digital stewardship approach to cultivating technological literacy, with digital stewardship defined as the competence to select and support the most appropriate technological solution based on its purpose and the needs of a particular community (Wenger et al., 2009). Within this course, ETCs are encouraged to engage, explore, explain, elaborate, and evaluate the course materials and content with their Critical Friends to become competent in choosing, adapting, and utilizing technological tools to solve problems in STEM/STEAM educational communities.

This 15-week course comprises three core themes: (1) coding for CT, modeling, and digital literacy, (2) EDP to solve problems grounded in human-centered empathy, and (3) learning about childhood and STEAM integration. The first theme allowed ETCs to experience various task-based coding platforms, such as Code.org’s Hour of Code Dance Party, web-based robot simulation RoboBlockly, and Etoys by MIT’s Media Lab, to understand and demonstrate CT in action through coding (thus, making thinking visible). Within the second theme, ETCs discussed and worked on engineering designs to meet the authentic needs of partner communities, grounded in human-centeredness (e.g., histories, needs assessments, available resources, STEAM approaches in action). The last theme involved ETCs designing an interdisciplinary 5E STEAM lesson plan as a pair, called Critical Friends, peer feedback, STEAM Family Night rehearsals, and the actual events, providing both in person at the Botanical Gardens and through a virtual Zoom platform with AATLC.

ETCs accumulated their learning through various assignments, including weekly readings, reflections, fishbowl debates, STEM lab field trips, STEAM education site visits, discussions, a Learning Technology Show-and-Tell activity, and the STEAM Family Night community learning experience project. The Learning Technology Show-and-Tell activity required ETCs to work with Critical Friends to demonstrate and explain their use of children-appropriate learning technology to overcome challenges linked to CT and EDP across the 5E Cycle. We posit that CT is best cultivated through EDP, while the 5E Learning Cycle provides a pedagogical structure that supports learners’ engagement in the iterative processes of engineering design. For example, some ETCs explained that using Scratch for block programming could create a game like “apple catching,” where children can apply EDP through testing and refining, such as by changing the speed or sprites—characters or objects that can be programmed in Scratch. Other ETCs demonstrated that designing a maze in which the Ozobot reaches the finish with the fewest codes can teach children algorithms through sequencing and debugging when the Ozobot does not work as expected. These design-oriented activities included 3D visualization, non-linear processing, problem representation, and hand-drafting—components that support, but do not replace, explicit spatial skills training (S. A. Sorby, 2019; S. Sorby et al., 2026).

Approaching the end of the semester, ETCs needed to plan and teach a technology-enhanced STEM/STEAM activity at the STEAM Family Night, a public event held at

the Botanical Garden and partnered with the garden's education department. After the site visit, ETCs needed to write a peer-reviewed lesson plan that indicates how their activity followed the 5E Learning Cycle, how it supported CT and EDP, how the learning objectives connected to creativity, problem-solving, or collaboration, and how the content aligned with the Standards. A rehearsal night was held to receive feedback from Critical Friends—classmates and program partners. The two-hour STEAM Family Night hosted approximately 51 local family members. ETCs reflected on this experience afterward.

Theoretical Lens

Following the theoretical framework taxonomy in engineering education (Magana, 2022), the design of TwT and this study are guided by the Communities of Practice (CoP) framework (Wenger, 2000), which serves as both a pedagogical and theoretical foundation. The CoP framework theorizes learning through a social lens, arguing that learning is realized through practice in relation to others and the real world, meaning-making of knowledge and understanding of one's identity based on daily lived experiences, and the formation of communities as each participant maintains membership by competently playing an expected role through agreed-upon means toward common goals and values (Wenger, 2000). It challenges the perception of "community" as merely a group of people assigned a label, title, or organization. Instead, a CoP comes into being through collective effort and participation in achieving commonly expected social purposes (Wenger, 2000). CoP views learning as a process of participating in what members consider meaningful and reifying meaning through participation; therefore, members of a CoP learn through ongoing participation in tasks and reify knowledge and its meaning in relation to the world (Wenger, 2000).

The CoP is widely applied in theorizing teacher education. The CoP between school and university helped teacher candidates develop classroom teacher identities grounded in a shared vision and values among teacher candidates and schoolteachers (Truscott & Barker, 2020). Online CoP helped teacher candidates build self-confidence and open-mindedness, as they felt encouraged by the online community to express their opinions (Inel Ekici, 2017). A recent study on the CoP combined with group lesson study also shows an increase in pre-service teachers' self-efficacy, as the activities helped them enhance classroom management and instructional skills, build teacher identity, recognize real-world problems, and grow through collaboration (Sonsupap et al., 2025). This study positions "participation" as the foundation of community formation, identity development, and learning.

Concurrently, given that the TwT pedagogical model is in an initial exploratory stage, participation is operationalized as a negotiable process. This perspective acknowledges that the engagement of CoP members is fluid, contextually meaningful, and fundamentally situation based. Specifically, within TwT, the CoP developed across the semester through repeated participation around the shared goal of designing meaningful PreK-5 STEAM experiences. ETCs worked regularly with Critical Friends to explore technologies, develop and revise lesson plans, and prepare for Family Night, while STEM scientists, STEAM educators, and community partners provided disciplinary, pedagogical, and contextual feedback. These recurring interactions created opportunities for participants to negotiate meaning, refine their roles, and work toward the shared goal of supporting children's STEAM learning.

This study adopts a Design-Based Implementation Research (DBIR) conceptual framework, utilizing its core principles to define and interpret TwT. The main principles of DBIR in education feature collaborative, iterative efforts among researchers, practitioners, and other stakeholders to develop theoretical and practical knowledge through design and testing to address persistent problems in classroom educational practices and sustain

impacts in educational and scholarly fields (LeMahieu et al., 2017). DBIR has been used to propagate a curriculum exemplified by Underwood and Kararo's (2021) case, in which nine institutions propagated a DBIR-based, undergraduate-level, innovative general chemistry curriculum, and the semester-end outcomes were used for research and curriculum modification. A successful DBIR case in teacher professional development reports fostering routine and interactive norms, co-constructed shared goals, co-instruction, and the leveraging of partners' expertise and experiences (Santagata et al., 2026). As an initial exploration grounded in DBIR, the TwT curriculum and this study leverage iterative design to provide practical insights for field implementation and long-term, sustainable research.

In addition, the TwT adopts Storey and Richard's (2015) conceptualization of Critical Friends, which defines Critical Friends as trusted, empathetic, and supportive friends who provide constructive feedback from an alternative lens on the tasks rather than the person. Further, Critical Friends need to ask proactive questions and provide critique of the tasks based on a sufficient and comprehensive understanding of the task's context and the desired outcomes (Storey & Richard, 2015). The Critical Friends routine is found to be effective for novice teachers' reflective development and professional growth (Farangi et al., 2026). Moreover, structured observation and feedback protocols can guide and enhance collaboration among Critical Friends (Odabaşı Çimer et al., 2025). As a conceptual framework, the Critical Friend routine—where ETCs provide peer feedback—serves to interpret a micro-CoP within the TwT curriculum to enhance learning as a social practice. In this study, the Critical Friends conceptual framework also guided the collection and examination of data from open-ended survey questions regarding ETCs' experiences with and feedback on peer collaboration in TwT.

3. Methods

3.1. Participants

The participants were ETCs enrolled in TwT for the fall 2025 semester. A total of 23 ETCs consented and completed the pre-survey, and 13 of the 23 consented and completed the post-survey. Before the semester began, most ETCs had less than 21 h of field/practicum teaching experience, used technology for teaching only sometimes or rarely, had no engineering design experience, had only basic coding experience, and felt neutral about learning new technology on their own. The pre- and post-survey participants showed similar demographic patterns descriptively. Among the participating ETCs, half were juniors, followed by seniors and sophomores in both pre- and post-surveys. Over 80 percent were female and white in both pre- and post-surveys.

When comparing respondents who completed only the pre-survey with those who completed both surveys, baseline data showed similar distributions. Among the 23 total pre-survey respondents, 43% had some ED experience, while 48% had none; similarly, nearly half of the 13 respondents who completed both surveys reported some or no ED experience prior to the semester. This pattern also extended to field experience: 65% of the 23 total pre-survey respondents and 62% of those who completed both surveys had fewer than 20 h of field experience before the semester.

By the end of the semester, the post-survey showed that the participating ETCs gained more field experience ranging from 21 to 80 h, used technology for teaching more often, had engineering design experience to varying extents, had at least basic coding experience, and still felt neutral about learning new technology on their own. Because the post-survey participants may have been more engaged students or higher-achieving students, the potential for selection bias must be acknowledged.

3.2. Methodological Approach, Data Collection, and Data Analysis

To meet Agarwal and Raju's (2025) quality standards for empirical studies using mixed-methods designs in engineering education, this section begins with the rationale for and type of MMR design employed. This study utilizes a parallel mixed-methods research (MMR) approach (Teddlie & Tashakkori, 2010) to capture ETCs' comprehensive and nuanced perceptions of their semester-long learning, teaching, and collaborative experiences. Given that the quantitative data rely on participants' self-perceptions, triangulating and supplementing these findings with interpretivist insights is essential. Integrating positivist and interpretivist perspectives allows for a richer exploration of the complex nature of human experiences and perceptions within project-based, community-partnered activities.

A parallel MMR conducts the quantitative and qualitative strands simultaneously; namely, the collection and analysis of each strand are separately conducted nearly at the same time, and the integration for a meta-inference based on both findings occurs after obtaining both quantitative and qualitative findings (Teddlie & Tashakkori, 2010). Because integration occurred only after both quantitative and qualitative results were finalized for meta-inference—rather than using one strand to inform the design of the other—this study is classified as a parallel (or concurrent) MMR design.

This study uses a survey method (Creswell & Creswell, 2018) to collect both quantitative and qualitative data. A pre-survey was distributed on the first day of the class meeting in the 2025 fall semester, and a post-survey was distributed at the end of the semester. An additional survey was administered following the STEAM Family Night event. The data analysis did not occur until all survey data had been collected. Additional de-identified TwT artifacts, such as lesson plans and Tech show-and-tell posters, were also collected to triangulate the findings.

Besides the demographic questions, the pre- and post-course surveys include 1–5 Likert Scales, self-rated 1–100 scales, and open-ended questions and consist of four sections related to the research questions: (1) experience and familiarity with integrating technology for maker-based activity planning in PreK-12 STEM context, (2) confidence with self-learning new technologies, integrating technology into PreK-12 STEM, and the capability of technological integration to enhance problem-solving and creativity, (3) perceptions of computational thinking and engineering design, and (4) perceived ability and confidence in teaching 21st century skills, such as creativity, collaboration, and problem-solving through technology in STEM education. The same questions in the four sections and the demographic questions are included in both pre- and post-surveys. Additional open-ended and Likert-scale questions are included only in the post-survey, allowing participating ETCs to elaborate on and evaluate their experiences with the semester-long community-partnered learning experience.

The post-Family Night survey consisted primarily of open-ended questions alongside select multiple-choice items and artifact upload prompts—designed to gather ETCs' perspectives on the event and their overall experiences with TwT. The survey asked ETCs how facilitating activities deepened their understanding of CT and EDP, which CT and EDP components they observed children using, and whether the experience altered their views on integrating CT or EDP into elementary STEAM education. ETCs were required to both identify these elements and elaborate on their responses. Additional items captured feedback they received, the role of Critical Friends, challenges associated with teaching children in informal spaces, experiences with 5E integration, personal gains, and perceptions of their contributions to the community.

The survey instrument was developed by the research team specifically for the TwT course and was not adapted from or drawn directly from a previously validated instrument. Survey items were intentionally aligned with the course learning outcomes, the theoretical

frameworks guiding the study (Communities of Practice, Design-Based Implementation Research, and Critical Friends), and the three research questions. To support the clarity, relevance, and alignment of the survey items, the survey was iteratively reviewed by the research team, whose expertise spans science education, STEM education, educational technology, and teacher education, to ensure the clarity, relevance, and alignment of survey items with the intended constructs and course learning outcomes. Because the quantitative component primarily consisted of single-item measures assessing distinct constructs, together with qualitative open-ended questions, internal consistency statistics (e.g., Cronbach's alpha) were not calculated, as they were not appropriate for the structure and intended purpose of the instrument.

The responses to the 1–5 Likert Scale and 1–100 scale questions were analyzed using a quantitative approach, with descriptive analysis to understand the overall tendency, and two methods: a paired *t*-test and linear mixed models (LMMs) to determine whether there is a statistical difference between the pre- and post-responses. Due to differences in data size between the pre- ($n = 23$) and post-responses ($n = 13$), this study used two methods: a traditional paired *t*-test and an LMM to double-verify the results and report only those confirmed by both methods. The LMM analysis used survey completion time (pre or post) as the fixed effects variables and the participant (each assigned an ID number) as random effects grouping variables. The open-ended survey responses (pre-survey $n = 5$, post-survey $n = 13$, and post-Family Night survey $n = 19$) were analyzed using a reflexive thematic approach (Clarke & Braun, 2017). To capture diverse perspectives, the coding team consisted of three coders: two specializing in education and one specializing in human and family development. Operating within an interpretive paradigm, the coders rejected predetermined codebooks in favor of a constructivist process of developing initial codes through repeated readings of the narrative data and subsequently grouped these codes into meaningful themes that addressed the research questions. Specifically, the coders individually reviewed and discussed the developing codes and themes, refining their interpretations through discussion of similarities, differences, and relationships across the narrative responses. Lastly, a joint display analysis method (Creswell & Plano Clark, 2019) was used to integrate quantitative and qualitative findings. Quantitative results were aligned with corresponding qualitative codes and themes to examine convergence, complementarity, and discrepancies across the two strands. These comparisons informed the meta-inferences reported in the integrated results.

4. Results

4.1. Quantitative Results

Quantitative findings reported below reflect ETCs' self-reported perceptions rather than observed behavioral changes or performance. According to the 1–5 Likert Scale and the 0–100 Scale results, ETCs perceived that TwT has helped them gain more hands-on engineering and maker-based project experience, as well as familiarity with educational technology in STEM/STEAM. The statistical results also show that ETCs perceived themselves as having gained confidence in integrating technology into STEM teaching and in facilitating learning through CT and EDP, as they have gained a better understanding of these concepts. They also perceived themselves as having gained the ability to design hands-on, technology-based activities for creativity, to facilitate collaboration through technology, and to foster problem-solving with technology. Lastly, ETCs perceived community-based activities as meaningful and motivating, contributing to their STEM/STEAM educator preparedness and identity formation.

4.1.1. Digital Stewardship/Technological Literacy for Future STEM/STEAM Educators

ETCs' experience with hands-on engineering and maker-based projects and their self-rated familiarity with educational technology in STEM have increased significantly after the semester. Based on the descriptive statistics, ETCs' experience with hands-on engineering or maker-based projects shows higher mean scores (3.26–4.23) and lower standard deviations (0.86–0.83) when comparing pre- and post- results. According to the LMM, $F(1, 12.42) = 17.76$, $p = 0.001$, and the paired t -test, $t(12) = 3.25$, $p = 0.007$, $d = 0.90$ the difference in the pre- and post-survey mean scores is statistically significant.

On a 0–100 scale, the mean for participating ETCs' self-rated familiarity with educational technology in STEM has increased (50.96–73.62), with a decreased standard deviation (19.87–8.08). According to the LMM, $F(1, 16.05) = 15.51$, $p = 0.001$, and the paired t -test, $t(12) = 4.55$, $p < 0.001$, $d = 1.26$, the difference in participants' self-rated familiarity with STEM educational technology is statistically significant. The statistical results are shown in Table 1 below.

Table 1. ETCs' pre- and post-perceptions of their digital stewardship for future STEM educators.

Survey Item	Descriptive	LMM	Paired t -Test	Cohen's d
Have participated in hands-on engineering design or maker-based projects	M: 3.26–4.23 SD: 0.86–0.83	$F(1, 12.42) = 17.76$, $p = 0.001$	$t(12) = 3.25$, $p = 0.007$	$d = 0.90$
Rate familiarity with educational technology in STEM	M: 50.96–73.62 SD: 19.87–8.08	$F(1, 16.05) = 15.51$, $p = 0.001$	$t(12) = 4.55$, $p < 0.001$	$d = 1.26$

By the end of the semester, ETCs had become more confident in technology integration. The increase in the mean scores for ETCs' self-rated confidence in integrating technology into STEM teaching and learning is statistically significant in both the paired t -test and LMM. On a 0–100 scale, ETCs' self-rated confidence in integrating technology into STEM teaching and learning is higher (54.61–74.92), with a smaller standard deviation (22.05–13.67). In the LMM, the difference is statistically significant, $F(1, 8.48) = 13.97$, $p = 0.005$. The paired t -test also shows statistical significance for the difference between the pre- and post-surveys, $t(12) = 2.90$, $p = 0.013$, $d = 0.80$. The statistical results are shown in Table 2 below.

Table 2. ETCs' pre- and post-self-confidence in their digital stewardship for STEM educators.

Survey Item	Descriptive	LMM	Paired t -Test	Cohen's d
Rate your confidence in integrating technology into STEM teaching and learning.	M: 54.61–74.92 SD: 22.05–13.67	$F(1, 8.48) = 13.97$ $p = 0.005$	$t(12) = 2.90$, $p = 0.013$	$d = 0.80$

Regarding integrating technology for 21st-century learning and instruction in creativity, problem-solving, and collaboration, after the semester, ETCs reported gaining confidence and the ability to use technology to facilitate these skills. For the 1–5 Likert Scales, the increase in ETCs' confidence in designing hands-on, technology-based activities for creativity is statistically significant in both the paired t -test and the LMM. The post-survey mean score is higher (3.35–4.31), with a smaller standard deviation (1.03–0.75). The LMM confirms the increase, $F(1, 12.17) = 27.62$, $p < 0.001$, and the paired t -test, $t(12) = 2.56$, $p = 0.025$, $d = 0.71$.

On a 0–100 scale, the increases in the mean scores for ETCs' self-rated ability to design technology-enhanced STEM activities, confidence in facilitating collaboration through technology, and confidence in fostering problem-solving with technology are higher and statistically significant in both paired t -tests and LMMs.

The post-survey mean score for ETCs' self-rated ability to design technology-enhanced STEM activities is higher (40.22–80.69), with a smaller standard deviation (24.25–11.56). The mean score for their self-rated confidence in facilitating collaboration through technology is higher (59.44–85.69), and the standard deviation is smaller (26.87–12.21). Lastly, ETCs' self-rated confidence in fostering problem-solving with technology is higher (60.44–86.15), and the standard deviation is smaller (24.27–12.13).

These increases have statistical significance confirmed by the LMM: self-rated ability to design technology-enhanced STEM activity, $F(1, 11.92) = 77.50, p < 0.001$, confidence in facilitating collaboration through technology, $F(1, 34) = 11.01, p = 0.002$, and confidence in fostering problem-solving with technology, $F(1, 10.34) = 25.12, p < 0.001$. In the paired *t*-test, the differences in the mean scores also show statistical significance: self-rated ability to design technology-enhanced STEM activities, $t(12) = 4.92, p < 0.001, d = 1.37$; self-rated confidence in facilitating collaboration through technology, $t(12) = 2.87, p = 0.014, d = 0.80$; and self-rated confidence in fostering problem-solving with technology, $t(12) = 3.14, p = 0.009, d = 0.87$. The statistical results are shown in Table 3 below.

Table 3. ETCs' pre- and post-perceptions of and confidence in teaching 21st-century skills through technology-enhanced STEM activities.

Survey Item	Descriptive	LMM	Paired <i>t</i> -Test	Cohen's <i>d</i>
Confident in designing hands-on, technology-based activities that promote creativity	M: 3.35–4.31 SD: 1.03–0.75	$F(1, 12.17) = 27.62$ $p < 0.001$	$t(12) = 2.56, p = 0.025$	$d = 0.71$
Rate ability to design technology-enhanced STEM activity	M: 40.22–80.69 SD: 24.25–11.56	$F(1, 11.92) = 77.50$ $p < 0.001$	$t(12) = 4.92, p < 0.001$	$d = 1.37$
Rate confidence in facilitating collaboration through technology	M: 59.44–85.69 SD: 26.87–12.21	$F(1, 34) = 11.01$ $p = 0.002$	$t(12) = 2.87, p = 0.014$	$d = 0.80$
Rate your confidence in fostering problem-solving with technology	M: 60.44–86.15 SD: 24.27–12.13	$F(1, 10.34) = 25.12$ $p < 0.001$	$t(12) = 3.14, p = 0.009$	$d = 0.87$

4.1.2. ETCs' Perceptions of CT and EDP Confidence and Competence

In this section, the increase across all Likert Scale results is statistically significant in both the paired *t*-test and the LMM. All mean scores for the 1–5 Likert Scales in this section were below 3 in the pre-survey. The mean score for ETCs' understanding of CT in PreK–12 education increased (2.78–4.23), while the standard deviation was smaller (0.90–0.44). The mean score for their understanding of EDP is higher (2.96–4.08), while the standard deviation is smaller (0.83–0.64). The mean score for their confidence in facilitating learning through CT is higher (2.83–4.08), and the standard deviation is smaller (0.78–0.64). Lastly, ETCs' confidence in facilitating learning through EDP is higher (2.70–4.08), while the standard deviation is smaller (0.88–0.49).

Running the LMM shows that the difference in the mean scores for all the Likert Scale post-survey responses in this section show statistical significance compared with those in the pre-survey: ETCs' self-rated understanding of what CT means in PreK–12 education is statistically significant, $F(1, 11.11) = 99.28, p < 0.001$, self-rated understanding of what EDP means in PreK–12 education, $F(1, 34) = 17.83, p < 0.001$, self-rated confidence in facilitating learning through CT, $F(1, 14.02) = 24.56, p < 0.001$, and self-rated confidence in facilitating learning through EDP, $F(1, 34) = 27.22, p < 0.001$.

In the paired *t*-test, the differences in the mean scores for all the Likert Scale post-survey responses in this section show statistical significance compared with those in the pre-survey: ETCs' perceived understanding of CT in PreK–12 education, $t(12) = 6.50, p < 0.001, d = 1.80$; perceived understanding of EDP in PreK–12 education, $t(12) = 6.06,$

$p < 0.001$, $d = 1.68$; confidence in facilitating learning through CT, $t(12) = 3.61$, $p = 0.004$, $d = 1.00$; and confidence in facilitating learning through EDP, $t(12) = 4.57$, $p < 0.001$, $d = 1.27$. The statistical results are shown in Table 4 below.

Table 4. ETCs' pre- and post-perceptions of their CT and EDP understanding and confidence in teaching CT and EDP in PreK-12 education.

Survey Item	Descriptive	LMM	Paired <i>t</i> -Test	Cohen's <i>d</i>
Understand what computational thinking means in PreK-12 education	M: 2.78–4.23 SD: 0.90–0.44	$F(1, 11.11) = 99.28$ $p < 0.001$	$t(12) = 6.50$, $p < 0.001$	$d = 1.80$
Understand what engineering design means in PreK-12 education	M: 2.96–4.08 SD: 0.83–0.64	$F(1, 34) = 17.83$ $p < 0.001$	$t(12) = 6.06$, $p < 0.001$	$d = 1.68$
Confident in facilitating student learning through computational thinking practices	M: 2.83–4.08 SD: 0.78–0.64	$F(1, 14.02) = 24.56$ $p < 0.001$	$t(12) = 3.61$, $p = 0.004$	$d = 1.00$
Confident in facilitating student learning through engineering design challenges	M: 2.70–4.08 SD: 0.88–0.49	$F(1, 34) = 27.22$ $p < 0.001$	$t(12) = 4.57$, $p < 0.001$	$d = 1.27$

On the 1–100 scale, all post-survey responses show higher mean scores and smaller standard deviations, with statistical significance confirmed by both the LMM and the paired *t*-test. The mean scores were all below 50 in the pre-survey. The mean score for ETCs' self-rated understanding of CT is higher (42.09–78.39) in the post-survey, with a smaller standard deviation (25.15–10.62). The mean score for their self-rated understanding of EDP is higher (36.35–76.46), with a smaller standard deviation (21.32–15.86). The mean score for self-rated confidence in teaching and facilitating CT is higher (38.91–72.39), with a smaller standard deviation (24.62–12.65). Lastly, the mean score for self-rated confidence in teaching and facilitating EDP is higher (31.96–71.46), with a smaller standard deviation (22.64–14.20).

The differences in the mean scores for all these post-survey 0–100 Scale responses in this section show statistical significance compared with those in the pre-survey in the LMM: participants' self-rated understanding of CT, $F(1, 9.89) = 29.20$, $p < 0.001$, self-rated understanding of EDP in the LMM, $F(1, 34) = 34.91$, $p < 0.001$, self-rated confidence in teaching or facilitating CT, $F(1, 10.75) = 28.55$, $p < 0.001$, and self-rated confidence in teaching or facilitating EDP, $F(1, 16.28) = 34.17$, $p < 0.001$.

The differences in the mean scores for all post-survey 0–100 Scale responses in this section show statistical significance compared with those in the pre-survey in the paired *t*-test: self-rated understanding of CT, $t(12) = 3.99$, $p = 0.002$, $d = 1.11$, self-rated understanding of EDP, $t(12) = 5.76$, $p < 0.001$, $d = 1.60$, self-rated confidence in teaching or facilitating CT, $t(12) = 3.60$, $p = 0.004$, $d = 1.00$, and self-rated confidence in teaching or facilitating EDP, $t(12) = 5.10$, $p < 0.001$, $d = 1.41$. The statistical results are shown in Table 5 below.

Table 5. ETCs' pre- and post-self-rated CT and EDP understanding and confidence.

Survey Item	Descriptive	LMM	Paired <i>t</i> -Test	Cohen's <i>d</i>
Rate your understanding of computational thinking	M: 42.09–78.39 SD: 25.15–10.62	$F(1, 9.89) = 29.20$ $p < 0.001$	$t(12) = 3.99$, $p = 0.002$	$d = 1.11$
Rate your understanding of engineering design	M: 36.35–76.46 SD: 21.32–15.86	$F(1, 34) = 34.91$ $p < 0.001$	$t(12) = 5.76$, $p < 0.001$	$d = 1.60$
Rate your confidence in teaching or facilitating computational thinking	M: 38.91–72.39 SD: 24.62–12.65	$F(1, 10.75) = 28.55$ $p < 0.001$	$t(12) = 3.60$, $p = 0.004$	$d = 1.00$
Rate your confidence in teaching or facilitating engineering design	M: 31.96–71.46 SD: 22.64–14.20	$F(1, 16.28) = 34.17$ $p < 0.001$	$t(12) = 5.10$, $p < 0.001$	$d = 1.41$

4.1.3. STEM/STEAM Educator Readiness and Identity Development Through Community-Based Learning Activities

The 13 ETCs rated their experience of participating in community-based learning activities over the semester with a mean score of 4.77 and a standard deviation of 0.44. The mean score for their rated meaningfulness of the community-based component compared to a traditional college course held only on campus is 4.69, with a standard deviation of 0.48. The mean score for participating in community-based teaching experiences' influence, such as STEAM night and field trips, on their interest in designing similar activities as a future teacher is 4.69, with a standard deviation of 0.48. The distributions are displayed in Figure 1 below.

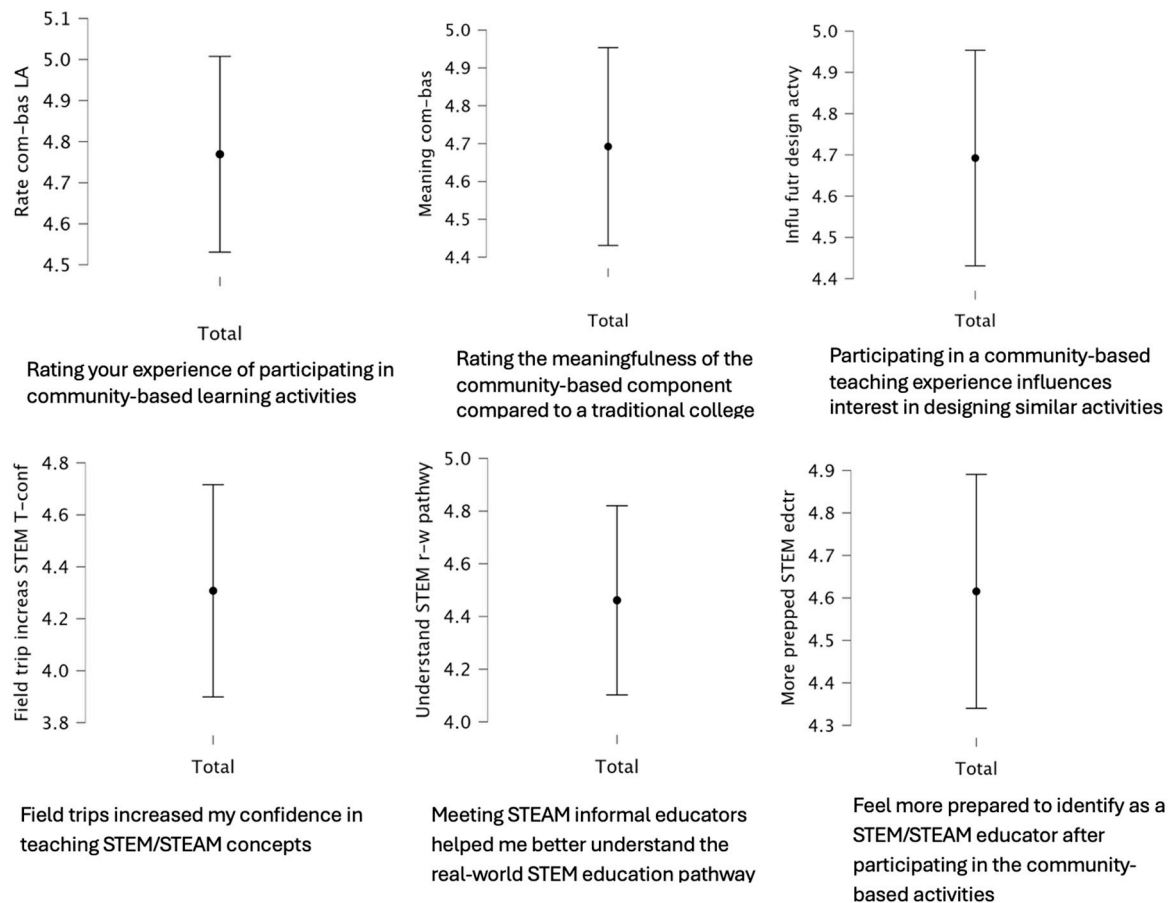


Figure 1. Interval plots of ETCs' perceptions and ratings of community-based learning.

The mean score for ETCs rated their agreement with the statement that the field trips (e.g., engineering labs, maker spaces, partner organizations) increased their confidence in teaching STEM/STEAM concepts is 4.31, with a standard deviation of 0.75. The mean score for their agreement with the statement that meeting STEAM informal educators helped them better understand real-world STEM education pathways is 4.46, with a standard deviation of 0.66. Lastly, the mean score for whether they feel more prepared to identify as a STEM/STEAM educator after participating in the community-based activities (e.g., critical friends weekly discussion leads, serving as contrarians, field trips, engineering labs, meeting informal educators, fishbowl community debate, STEAM family night events) is 4.62 with a standard deviation of 0.51. The distributions are displayed in Figure 1 below.

4.2. Qualitative Results

Qualitative results are based on ETCs' narrative data, which provide insights into their experiences with TwT. By taking this course, ETCs started to recognize TwT as a "new way to learn," a pedagogy. They became more aware of aligning their lesson plans with the Standards and differentiating between teaching about technology and teaching with technology. Regarding the community-based activities, ETCs found them motivating and meaningful in helping them see technology as more than abstract concepts but as useful problem-solving tools and career paths. The community-based activities also helped them become better prepared as future STEM/STEAM educators by teaching real students and collaborating with peers and experts. Lastly, ETCs reported deepening their understanding of CT and the EDP through direct engagement with these processes in TwT and through observing children's behaviors during STEAM Family Night.

4.2.1. Perceptual Changes Before and After the Semester

Before the semester began, the 23 ETCs understood "Toy with Technology" by its course title as "play around", "explore", "experiment", and "having fun", focusing on hands-on experiences and being open to multiple possibilities. They considered this course to be about heuristically discovering new technological platforms and applications to enhance learning, specifically skills such as creativity, problem-solving, critical thinking, collaboration, the learning process, and the limitations of technology. After the semester, the 13 ETCs recognized "Toy with Technology" as a new pedagogy of learning, maintaining that it lets learners discover how new technologies work by exploring and experimenting with them in a fun, low-pressure environment, emphasizing creativity and problem-solving, and inspiring future classroom technological implementation to enhance learning.

Aligning technological integration with Standards was absent in the perceived challenges in the pre-survey but appeared in the post-survey answers. The majority of ETCs had not formed a clear goal on the first day. The 5 elaborated responses in the pre-survey convey three ways ETCs relate technology to enhancing teaching and learning: platform, application, and potential. The first one is about the "platform," as the participant hopes to learn about specific technological platforms. The second is the "way" to integrate technology into lessons. The last one is to explore the potential of technology to support non-STEM subjects. After the semester, the 13 ETCs reported that the goals they accomplished included becoming more confident in understanding technological tools and concepts, creating lesson plans aligned with Standards such as the Common Core and 5E, integrating technology into classroom practices, and understanding CT and EDP.

The post-survey shows ETCs' awareness of the difference between learning *about* technology and learning with technology in making a lesson plan for students of different ages. The majority did not have an answer on the first day regarding their anticipated challenges either. The 5 elaborated answers show three types of concerns: technological issues—the technology does not work or is unreliable; children's ability to handle technological use due to their young ages; and the difficulty of integrating technology with content knowledge and pedagogical purposes, especially in a creative way. After the semester, the ETCs indicated that one challenge is the need to learn unfamiliar technology before knowing how to integrate it into subject teaching, which takes time. Another major challenge is creating a lesson plan that is not about learning the technology but uses technology to facilitate age-appropriate learning. A lower initial confidence in technology was also a setback.

4.2.2. Perceptions of Community-Based Learning Experiences After the Semester

Working with real students and families at the STEAM Night, collaborating with Critical Friends and community partners, and field trips to the various locations are

considered most prominent of the community-based learning experience, as teaching real children helped ETCs see their work as meaningful, collaborating with Critical Friends and community partners helped them become better prepared for the STEAM Night and future career, and taking the field trips helped them gain more concrete and comprehensive insight into technology and STEM.

The STEAM Night contributed to ETCs' sense of becoming capable STEM/STEAM educators, as they had the opportunity to interact with students and families and to learn about programs from informal educators. ETCs enjoyed seeing their efforts become meaningful through children's genuine reactions and making an impact on communities when they came to support this event. However, ETCs also found it challenging to adapt to realities that did not align with their preparation and expectations, including children's unexpected reactions, behaviors, and age range.

ETCs enjoyed having Critical Friends and a consistent group to ask for help and critical advice, support each other, and bounce ideas off. ETCs felt better prepared through the Critical Friends routine because they had a group of trusted people to prepare and practice with, and useful resources. They conveyed that these collaborative opportunities made them become more proficient collaborators.

Additionally, field trips and lab visits with passionate engineers motivated ETCs to put greater effort into advocating STEM. Seeing STEM in real professional settings has influenced ETCs' interest and confidence in teaching STEM/STEAM, as they have had the opportunity to see technology as more than an abstract concept, as useful tools in real life, as a career path their future students might choose, and as advancing over time. Also, ETCs saw that technology did not have to be very complicated but could be simple coding, which motivated them.

4.2.3. How ETCs Knew They Had a Stronger Understanding of CT and EDP

ETCs reported that TwT deepened their understanding of the nature of CT, as it allowed them to support and observe children's learning. Specifically, they guided children in approaching questions logically, decomposing tasks, following algorithmic steps, testing results, exploring alternative solutions, and iterating for continuous improvement.

An ETC noted, *"Teaching my ScratchJr lesson helped me better understand the nature of Computational Thinking (CT) because I had to break each idea into simple, concrete steps that young learners could follow. Guiding students through building short programs highlighted how essential CT skills—like decomposition, pattern recognition, step-by-step algorithmic thinking, and iterative debugging—are in even the simplest coding tasks. Watching students test, revise, and problem-solve in real time made me realize that CT is not just about coding, but about logical reasoning, creativity, and experimenting to improve solutions."* Another ETC added, *"Teaching my activity helped me better understand that Computational Thinking is really about guiding students to think logically and step-by-step as they solve problems. Using the Indi robot made it clear that CT involves breaking a challenge into smaller parts, predicting what will happen, testing an idea, and then adjusting when something doesn't work as expected."*

ETCs were also able to identify children's CT behaviors when they were engaging in the activities. ETCs reported that, during the STEAM Family Night, they observed various CT behaviors among participating children. The Sequencing behaviors included utilizing tile colors to navigate to a target location, constructing objects designed for specific movements, arranging physical blocks sequentially, and using logic to determine robot paths. The Pattern-recognition behaviors included identifying color cues for robot navigation, recognizing geometric patterns to build structures, creating or drawing designs, identifying distinct shapes, and using block-based code to move across coordinates. The Algorithmic thinking behaviors included applying pre-planned code sequences, projecting robot paths

prior to execution, mapping movements grid-by-grid, and designing step-by-step paths to spell target words. As an ETC noted, *“Students had to think through where they wanted the Blue Bot to go before they sent it.”* The *Debugging behaviors* involved conducting trials, using failure as a learning mechanism for subsequent attempts, backtracking to correct errors, diagnosing programmatic faults to isolate solutions, and testing alternative approaches to achieve goals, with one example from an ETC’s observation: *“Moving backwards if the robot hit a wall, making it go a shorter distance.”* Finally, the *decomposition behaviors* consisted of systematically breaking complex problems into manageable components.

ETCs also reported applying the EDP throughout lesson planning and refinement, which helped them understand EDP. Specifically, they adapted initial designs to support diverse learning needs, guided children in questioning, prompted them to follow engineering steps, cultivated creative imagination, facilitated hands-on creation, and challenged students with more complex designs. Reflecting on the lesson plan process, an ETC noted, *“This experience deepened my understanding of the EDP because when we first created the lesson, there were areas that were not great, so we had to go back and improve them before doing the STEAM night event.”* Another ETC shared an observation on their instructional approach, remarking, *“I noticed that I would often ask students to try again, or to challenge themselves to make their design harder.”* Elaborating on student engagement, an ETC added, *“I watched students go through all of these steps as they considered what to build and imagined it, and then either followed a plan or devised their own steps to create their design. I even saw students improvise on the items they made or that were previously made.”*

ETCs also identified and reported children’s behaviors aligned with the EDP during the STEAM Night activities. According to their reports, children frequently asked goal-oriented questions—such as whether a robot could execute specific commands or how to make a vehicle move backward—alongside operational questions regarding technological tools and button functions. As an ETC observed: *“Students asked questions like: How can I make the car go backward? Could I make an airplane fly? How does this work? What do certain buttons do?”* The children also demonstrated high enthusiasm for creation, building diverse structures based on their designs, constructing airplanes or boats with Lego bricks, imagining and sharing narrative stories, and verbally expressing their design intentions. Furthermore, ETCs noted that children systematically planned and tested their ideas, corrected mechanical faults, iterated on designs when dissatisfied with the results, adjusted navigation paths, and engaged in continuous experimentation. Highlighting this iterative behavior, one ETC noted, *“They would start the Scratch and then redo what they started if something was wrong or if they didn’t like it.”* Another ETC wrote, *“Students improved the car that we gave them with more design.”*

4.3. Integrated Results

The joint display integrates quantitative findings with qualitative codes to demonstrate how the ETCs’ self-reported changes are further illuminated by their narrative responses. Beyond statistical interpretation, these qualitative reflections contextualize ETCs’ TwT experiences, clarifying the underlying meaning of their Likert-scale responses and identifying the factors contributing to these perceived changes from their own perspectives. Discrepancies between the numerical scores and the qualitative descriptions are also highlighted and reported. Table 6 presents the pre- and post-survey items, their corresponding statistical results, and the related post-survey qualitative codes.

Table 6. Synthesizing major findings & major themes.

Quantitative Major Results		Qualitative Major Codes	Themes
Participated in hands-on engineering design or maker-based projects	Pre-Mean = 3.26 Pre-SD = 0.86 Post-Mean = 4.23 Post-SD = 0.83 $p = 0.007$	Low-pressure exploration and learning-by-doing with technology; Troubleshooting and debugging as problem-solving practice; Pedagogical integration of technology into 5E/standards-aligned lesson design; Self-reported sense-making of CT and EDP through hands-on design	
Willingness to experiment with new technologies in teaching and learning on my own	Pre-Mean = 4.09 Pre-SD = 0.73 Post-Mean = 4.00 Post-SD = 0.58 $p = 0.83$	The need to learn unfamiliar technologies before integration, which required additional time, posed a major challenge	
Rate the meaningfulness of the community-based component compared to a traditional college course	Mean = 4.69 SD = 0.48	Exposure to informal STEM education programs and resources; Learning from community partners and informal educators; Translating informal STEM contexts into future classroom possibilities	Learning EDP concepts and how to teach them through participation
Agreement that participating in a community-based teaching experience influences interest in designing similar activities	Mean = 4.69 SD = 0.48	Benefit the community; benefit low-income communities; effective in engaging students in problem-solving; depends on whether resources are provided; still lacks confidence; difficult to coordinate; difficult to find volunteers; difficult to find access to robots	Understanding empathy-centered meaning of STEAM from professional and community partners
Agreement that field trips increased confidence in teaching STEM/STEAM concepts	Mean = 4.31 SD = 0.75	Meaning-making through interaction with children and families; Learning from children's real-time responses and creativity; Perceived community relevance and meaningful contribution	STEM/STEAM teacher identity informed by community-based experiences
Agreement that Meeting STEAM informal educators helped participants understand real-world STEM education pathways	Mean = 4.46 SD = 0.66	Technology as real-world, creative, and accessible practice; Demystifying technological complexity; STEM as a possible career pathway for future students; Need for clearer PK–5 pedagogical connections in expert outreach	
Agreement that participants felt more prepared to identify as STEM/STEAM educators after community-based activities	Mean = 4.62 SD = 0.51	Critical Friends as peer-supported preparation and feedback; Collaborative scaffolding through peers, partners, and class preparation time; Authentic teaching practice with real learners; Adaptive facilitation in response to children's age, behavior, and support needs; Emerging sense of STEM/STEAM educator readiness	

4.3.1. Learning EDP Concepts and How to Teach Them Through Participation

TwT enhanced ETCs' experience with engineering and maker-based projects, as evidenced by an increase in mean scores on a 5-point Likert scale, rising from ($M = 3.26$) on the pre-survey to ($M = 4.23$) on the post-survey. In their qualitative reflections, ETCs attributed these shifts to a low-pressure course environment that offered opportunities to collaboratively experiment, explore, and emphasize creativity and problem-solving. Engaging in these shared practices allowed ETCs to experience EDP firsthand, deepen their conceptual understanding of EDP, and explicitly connect those experiences to educational standards and the 5E instructional model through lesson plan practices.

4.3.2. Understanding Empathy-Centered STEAM from Professional and Community Partners

ETCs rated the community-based course component as highly meaningful ($M = 4.69$). Qualitative data revealed that field trips to STEM labs, maker spaces, and partner organizations allowed ETCs to view technology as a dynamic problem-solving tool and career pathway. Motivated by interactions with passionate engineers, ETCs realized how technology evolves to meet human needs. Ultimately, these immersive experiences helped ETCs develop a deeper understanding of purposeful technology and conceptualize empathy-centered STEAM within authentic contexts.

4.3.3. STEM/STEAM Teacher Identity Informed by Community-Based Experience

ETCs reported that community-based activities helped them gain confidence in teaching STEAM ($M = 4.31$), understand real-world STEM education pathways ($M = 4.46$), and feel more prepared to identify as future STEM/STEAM educators ($M = 4.62$). Multiple components within these activities contributed to these perceived gains. Most prominently, reflecting on genuine interactions with children and families and experiencing a sense of community impact helped ETCs envision themselves in professional teaching roles. Additionally, constructive peer feedback and introductions to informal STEM educational programs from community partners provided valuable insights and connected ETCs with professional networks, contributing to their teacher identity development.

4.3.4. Nuances in ETCs' Ratings and Narrative Responses Regarding Their Intention to Design Similar Activities in the Future

Although the self-reported mean score for ETCs' interest in designing similar activities was high ($M = 4.69$, $SD = 0.48$), the post-Family Night survey revealed a more nuanced, contradictory trend. Among the 19 respondents, only three expressed an outright willingness to design future activities, citing community benefits and the technology's effectiveness in engaging students and teaching problem-solving. Five ETCs conditioned their future involvement on the availability of necessary resources, while another five remained neutral due to a lack of confidence. In contrary, three respondents were unlikely to design future community-based activities due to coordination difficulties, volunteer shortages, and limited free access to robotics equipment. Despite these reservations, this final group still acknowledged the value of such initiatives, particularly for low-income communities.

4.3.5. Discrepancy Between ETCs' Rated Willingness to Experiment with New Educational Technologies Independently and Their Description of the TwT Learning Environment

Before the semester, ETCs rated their willingness to experiment with new technologies in teaching and learning independently ($M = 4.09$, $SD = 0.73$). After the semester, this mean score decreased slightly to 4.00 ($SD = 0.58$). Although this decrease was not statistically significant ($p = 0.83$), it is noteworthy because it contrasts with their qualitative descriptions of TwT as a low-pressure, fun environment designed for experimentation and discovery. One potential explanation for this divergence, based on their qualitative responses, is that ETCs found mastering certain technological tools more time-consuming than anticipated. Consequently, they may have preferred explicitly scaffolded instruction or collaborative peer exploration over independent experimentation.

5. Discussion

5.1. TwT as an Example of the CoP with a Critical Friends Routine

TwT exemplifies a curriculum innovation that embeds a Critical Friends routine within a CoP framework. Designed for continuous iteration, this model addresses critical TPP challenges, such as strengthening ETCs' self-reported conceptual understanding and fostering their teacher identity development. By grounding coursework in social practices, TwT actively engages all stakeholders—peers, educators, and community partners—in a shared mission to advocate for PreK–5 STEM/STEAM education through interconnected processes of learning, knowing, becoming, and belonging.

5.1.1. Learning CT and EDP Concepts and Empathy-Centered STEAM Through Social Participation

On the first day of the semester, participating ETCs reported a low conceptual understanding of CT and EDP, alongside limited confidence in facilitating these frameworks, with mean scores below 3.00 on a 5-point Likert scale. Conversely, by the end of the semester,

ETCs self-reported substantial growth, achieving mean scores above 4.00 across both dimensions. During the STEAM Family Night events, ETCs were able to identify children's CT and EDP behaviors. ETCs attributed these gains to immersive social activities, including participating in project-based learning and Critical Friends brainstorming, designed to meet authentic community needs. Therefore, this study provides initial empirical evidence that social practices have the potential to effectively develop ETCs' conceptual knowledge of CT and EDP, helping them bridge these abstract frameworks with technology-integrated PreK–5 STEM education.

Previous research on engineering education from a cognitive perspective demonstrates that multimedia sketching tools designed to externalize mental representations can effectively support the development of spatial skills required for problem-solving and successful engineering and other STEM fields (S. A. Sorby, 2019). Building on this foundation, the TwT model applies a CoP framework to redefine visualization practices—such as sketching and coding—as interactive, social activities while examining different types of outcomes (e.g., test-based performance measures versus participants' self-reported perceptions and narrative descriptions). By utilizing digital tools for thinking visualization alongside social scaffolding from community partners and Critical Friends, this model offers a promising framework for curriculum innovation within TPPs that is worthy of further empirical investigation.

5.1.2. STEM/STEAM Teacher Identity Informed by Participation and Lived Experiences

Consistent with prior research (Sonsupap et al., 2025; Truscott & Barker, 2020), this study highlights the potential of CoP to facilitate ETCs' professional identity development. Within the CoP framework, identity is forged through daily lived experiences and active engagement within a community (Wenger, 2000). Throughout the semester, ETCs engaged in authentic tasks, such as designing actionable 5E lesson plans aligned with educational standards to teach an authentic audience group at STEAM Family Night. They were encouraged to experiment and make autonomous pedagogical decisions based on constructive feedback from peers and community partners. Fundamentally, by witnessing STEM applications in real-life contexts, such as labs and a botanic garden education department, and experiencing community support, ETCs reported that they had developed a stronger understanding of what it means to be a future STEM/STEAM educator, translating these lived experiences into a stronger sense of professional identity.

5.1.3. CoP as Dynamic, Emerged by Participation for Iterative Innovation

Rather than treating CoP as a pre-determined entity, this study conceptualizes competent “participation” as the very foundation of the community. Following Wenger's framework (2000), a CoP emerges through the competent role fulfillment of its members, which requires participants to learn and develop competence over time. Crucially, these roles are dynamic rather than fixed, leaving space for members to negotiate meaning and adapt their responsibilities. Because TwT is an innovative, exploratory, pedagogical approach, each STEM/STEAM CoP is unique based on its contextual participation needs. For example, while some engineering partners initially failed to connect their domain expertise to elementary education—causing confusion for ETCs—this reflected their first-time participation in the collaboration, offering a clear baseline for future adjustments. However, the engineering partners fulfilled their roles in a different way, as ETCs reported that these partners helped them build practical connections between technology and real-world needs. This finding suggests that CoP has the potential to serve as a valuable theoretical framework for negotiating meaning during the iterative adjustment of roles and objectives—a process that may be vital for fostering need-based innovation.

5.1.4. Importance of Cultivating ETCs' Capability to Build Their Own CoPs

Although ETCs indicated a high mean score regarding their interest in designing future community-based learning activities, many raised practical concerns when asked to elaborate. Their interest and willingness appeared to be conditional upon the availability of sufficient resources; furthermore, a lack of technical and human support led some ETCs to express reluctance toward pursuing such activities. Despite this hesitation, participants acknowledged the value of community-based initiatives like STEAM Family Night, particularly for low-income communities. This shared appreciation may help explain the high quantitative mean score obtained when participants rated their interest without further open-ended elaboration. Overall, the ETCs' overarching concerns about support and resources highlight the importance of community collaboration, creative problem-solving, and empathy for others' needs. Cultivating ETCs' capacity to build their own CoPs may support the development of sustainable activities that provide meaningful educational access to children and families.

5.2. Limitations, Improvement and Future Direction as DBIR

First, a key limitation of this study is that the quantitative instrument did not undergo formal content validity testing, although it was aligned with the course outcomes, theoretical framework, and research questions. Second, this study is limited by a small sample size and a relatively high attrition rate, as the sample decreased from 23 pre-survey participants to 13 post-survey participants. This reduction in sample size limits the strength of our comparative findings and statistical inferences. Because these findings represent an initial exploration in this field, future research with larger sample sizes is needed to examine and extend these preliminary results.

Participant attrition occurred without a specific cause, likely because data collection relied on volunteers within a university course. Students are generally more willing to participate at the start of a semester than at the end. Consequently, researchers conducting classroom-based studies rather than controlled experiments are advised to employ a triangulated data collection strategy—incorporating student artifacts, field observation notes, and course submissions—to compensate for predictable attrition rates.

Future studies on problem-solving behaviors and performance could incorporate behavioral tracking strategies—such as eye-tracking and graphing of design steps during task-based activities—to evaluate learners' EDP competencies and extend existing foundational research (S. Sorby et al., 2026). Furthermore, to address the pressing need for explicit spatial skills instruction in PreK–12 curricula and TPPs, future research should build on existing scholarship regarding technology-enhanced spatial ability development. Early spatial skills preparation is important, given its potential to support long-term success in engineering and other STEM disciplines (Lane & Sorby, 2022; S. Sorby et al., 2026).

ETCs self-reported a significant increase in confidence in designing hands-on, technology-based creative activities. However, compared with collaboration and problem-solving, creativity—as a critical 21st-century skill—may appear more abstract for ETCs to self-assess and rate accurately. Future DBIR efforts could establish explicit criteria to define distinct dimensions of creativity, such as originality, elaboration, risk-taking, curiosity, imagination, and flexibility (Widyastuti et al., 2026). Integrating these dimensions into survey evaluation tools could provide candidates with a clearer framework for comparison and self-assessment.

Grounded in DBIR, this study also aims to contribute to field practices within TPPs and curriculum development. Because a CoP framework emphasizes spaces for the negotiation of meaning, future community-partnered endeavors should prioritize open communication regarding community partners' roles to better serve the overarching curricular objectives.

While ETCs typically engage with community partners under explicit expectations directly related to teaching practices, partners can collaborate with course instructors to ensure field experiences extend beyond narrow, task-oriented expectations. By co-designing these field experiences to help ETCs connect new real-world insights to classroom instruction, partners can foster a more context-grounded collaboration that deepens ETCs' pedagogical perceptions. Alongside broader scholarly efforts to prepare children for STEM/STEAM success, the TwT curriculum shows potential to equip ETCs with the capacity to foster computational and engineering design thinking through classroom- and maker-based activities.

Although ETCs described TwT as a low-pressure environment for experimentation, the curriculum did not increase their willingness to experiment with new technologies independently, possibly due to the social nature of the curriculum. Future models could incorporate targeted strategies within the CoP to build ETCs' willingness and confidence needed in autonomous technological experimentation. Given that experimentation is important in engineering, future programs should document and balance self-directed exploration with community-based social learning.

6. Conclusions

This study suggests that project-based, community-partnered activities have the potential to support ETCs' self-reported understanding of CT and EDP, and their capability to identify and describe learners' CT and EDP behaviors, perceived growth in technological literacy, and their self-reported emerging sense of readiness as future STEM/STEAM educators. ETCs reported having greater confidence in understanding the concepts of CT and EDP, understanding how these concepts relate to PreK-5 STEM/STEAM education, and knowing how to facilitate creativity, problem-solving, and collaboration through CT and EDP, as they engaged in CT and EDP processes during the project-based, community-partnered activities to meet authentic demands and observed children's CT and EDP behaviors while engaging with educational technologies. They also reported increased confidence in technology integration as they were encouraged to explore and experiment in a low-pressure learning environment, supported by Critical Friends whom they trusted to help improve learning and teaching outcomes. They also described field trips as helping them view STEM and technology as real-world, accessible, and connected to possible career pathways for their future students while also pointing to the need for clearer connections between expert-led STEM experiences and PreK-5 classroom practice. Lastly, ETCs reported feeling better prepared for future STEM/STEAM teaching as they had opportunities to teach real students, collaborate with peers and experts, view technology and coding as more approachable, and learn from children's real-time reactions in a community-based setting.

This study acknowledges several limitations. First, the findings are drawn from a small sample with a relatively high attrition rate; therefore, the data should be treated as preliminary insights that require further examination with larger future samples. Second, this study documents ETCs' self-reported perceptions and experiences within a single semester at a single institution. Future research using diverse outcome metrics across varied institutional contexts is necessary to rigorously test, iterate, and further evaluate the TwT model and its initial findings.

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development process and family engagement activities. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: All participants were informed about the study, and only those who provided consent were included. Any data from participants who did not provide consent were removed from the dataset prior to analysis.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

CoP	Communities of Practice
CT	Computational thinking
DBIR	Design-based implementation research
EDP	Engineering design process
ETCs	Elementary teacher candidates
LMMs	Linear Mixed Models
TPP	Teacher Preparation Program
TwT	Toy with Technology

References

- Abdurrahman, A., Maulina, H., Nurulsari, N., Sukanto, I., Umam, A. N., & Mulyana, K. M. (2023). Impacts of integrating engineering design process into STEM makerspace on renewable energy unit to foster students' system thinking skills. *Heliyon*, 9(4), e15100. [CrossRef] [PubMed]
- Agarwal, J., & Raju, G. (2025). Establishing quality standards for empirical studies using mixed-methods designs in engineering education research. *The International Journal of Engineering Education*, 41(3), 808–820.
- Bariyyah, K. (2021). Problem solving skills: Essential skills challenges for the 21st century graduates. *Jurnal EDUCATIO: Jurnal Pendidikan Indonesia*, 7, 71–80. [CrossRef]
- Bybee, R. W., & Landes, N. M. (1990). Science for life & living: An elementary school science program from biological sciences curriculum study. *The American Biology Teacher*, 52, 92–98. [CrossRef]
- Clarke, V., & Braun, V. (2017). Thematic analysis. *The Journal of Positive Psychology*, 12(3), 297–298. [CrossRef]
- Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.
- Creswell, J. W., & Plano Clark, V. L. (2019). *Designing and conducting mixed methods research* (3rd ed.). SAGE.

- Dankunprasert, S., Cojorn, K., Sonsupap, K., Choompunuch, B., Ranmechai, S., Nonsuwan, A., & Tongron, Y. (2025). Bridging knowledge and community: Innovative community-based learning to strengthen mathematic pre-service teachers' problem-solving competency. *Eurasia Journal of Mathematics, Science and Technology Education*, 21(10), em2720. [CrossRef] [PubMed]
- Deng, Y., Lucas, C., & Liu, W. (2026). A systematic review of design thinking implementations in higher engineering education. *European Journal of Engineering Education*, 1–41. [CrossRef]
- Denning, P. J., & Tedre, M. (2019). *Computational thinking*. MIT Press.
- Duffy, G., Sorby, S., & Bowe, B. (2024). Exploring the role of spatial ability in the mental representation of word problems in mathematics. *Frontiers in Education*, 9, 1346474. [CrossRef]
- Duran, L. B., & Duran, E. (2004). The 5E instructional model: A learning cycle approach for inquiry-based science teaching. *Science Education Review*, 3(2), 49–58.
- Falloon, G. (2024). Advancing young students' computational thinking: An investigation of structured curriculum in early years primary schooling. *Computers and Education*, 216, 105045. [CrossRef]
- Farangi, M. R., Nejadghanbar, H., & Bahraman, M. (2026). A mixed-methods investigation of critical friend groups as a tool for honing teachers' practice. *Cogent Education*, 13(1), 2610564. [CrossRef]
- Han, Z., Chen, C., Chiu, T. K. F., Qiu, K., Yang, L., Wang, Z., & Chan, K. K. H. (2026). As an end or as a means to an end: Positioning empathy in STEM education. *International Journal of STEM Education*, 13(1), 4. [CrossRef]
- Hoz, A. D. I., Melo, L., Cañada, F., & Cubero, J. (2024). Educational robotics for science and mathematics teaching: Analysis of pre-service teachers' perceptions and self-confidence. *Heliyon*, 10(21), e40032. [CrossRef] [PubMed]
- Inel Ekici, D. (2017). The effects of online communities of practice on pre-service teachers' critical thinking dispositions. *Eurasia Journal of Mathematics, Science and Technology Education*, 13(7), 3801. [CrossRef]
- Kosky, P., & Keat, W. (2020). *Exploring engineering: An introduction to engineering and design* (R. Balmer, Ed.; 5th ed.). Elsevier Science.
- Lane, D., & Sorby, S. (2022). Bridging the gap: Blending spatial skills instruction into a technology teacher preparation programme. *International Journal of Technology and Design Education*, 32(4), 2195–2215. [CrossRef]
- LeMahieu, P. G., Nordstrum, L. E., & Potvin, A. S. (2017). Design-based implementation research. *Quality Assurance in Education*, 25(1), 26–42. [CrossRef]
- Linh, N. Q., & Huong, L. T. T. (2021). Engineering design process in STEM education: An illustration with the topic “wind energy engineers”. *Journal of Physics: Conference Series*, 1835(1), 12051. [CrossRef]
- Magana, A. J. (2022). The role of frameworks in engineering education research. *Journal of Engineering Education*, 111(1), 9–13. [CrossRef]
- Mills, K. A., Cope, J., Scholes, L., & Rowe, L. (2025). Coding and computational thinking across the curriculum: A review of educational outcomes. *Review of Educational Research*, 95(3), 581–618. [CrossRef]
- Mourtos, N. J., DeJong Okamoto, N., & Rhee, J. (2004). Defining, teaching, and assessing problem solving skills. In *7th UICEE annual conference on engineering education* (pp. 1–5). UNESCO International Centre for Engineering Education. Available online: <https://www.sjsu.edu/people/nikos.mourtos/docs/UICEE%2004%20Mumbai.pdf> (accessed on 9 June 2026).
- Nava, I., & Park, J. (2021). Pre-Service STEM teachers and their enactment of community-stemproject based learning (C-STEM-PBL). *Journal of Higher Education Theory and Practice*, 21(9), 217–237. [CrossRef]
- NGSS Lead States. (2013). *Next generation science standards: For states, by states*. The National Academies Press.
- Odabaşı Çimer, S., Şahin, İ., Cengiz, C., Batman, D., & Alev, N. (2025). Critical friends group as a continuing professional development model: Turkish teachers' experiences. *Teaching and Teacher Education*, 166, 105177. [CrossRef]
- Raju, G. M., Feldkamp, P., & Gaskins, W. (2024). Factors shaping students' attitude and persistence after participating in a summer physics course—a mixed methods study. *Journal of STEM Education*, 25(2), 61–68. [CrossRef]
- Santagata, R., Kimmerling, C., Fuentes Acevedo, P., & Liu, J. (2026). Conducting research on teacher professional development in partnership with educators: Promises, tensions and opportunities. *Journal of Curriculum Studies*, 58(2), 338–356. [CrossRef]
- Schina, D., Valls-Bautista, C., Borrull-Riera, A., Usart, M., & Esteve-González, V. (2021). An associational study: Preschool teachers' acceptance and self-efficacy towards educational robotics in a pre-service teacher training program. *International Journal of Educational Technology in Higher Education*, 18(1), 28. [CrossRef] [PubMed]
- Shim, S. W. (2025). Cultivating empathy in STEM: A conceptual framework for multicultural empathic design in STEM education. *Journal of sTEm Teacher Education*, 59(1), 2. [CrossRef]
- Sonsupap, K., Cojorn, K., Choompunuch, B., Intakanok, C., & Seesom, C. (2025). Exploring pre-service teachers' self-efficacy: The impact of community of practice and lesson study. *Education Sciences*, 15(10), 1357. [CrossRef]
- Sorby, S., Duffy, G., Parkinson, J., Raju, G., Lynch, J., & Asghar, M. (2026). Educating the next generation of engineers: Spatial thinking is key to their success. *Education Sciences*, 16(6), 847. [CrossRef]
- Sorby, S. A. (2019). Assessment of a “new and improved” course for the development of 3-D spatial skills. *Engineering Design Graphics Journal*, 69(3). [CrossRef]
- Storey, V. A., & Richard, B. (2015). The role of critical friends in supporting institutional change: Developing a collaborative environment. *Journal of Applied Research in Higher Education*, 7(2), 412–428. [CrossRef]

- Teddlie, C., & Tashakkori, A. (2010). *Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioral sciences*. SAGE.
- Topçu, M. S., & Çiftçi, A. (2023). Co-design and implementation of community-based engineering enriched science units: Exploration of pre-service science teachers' professional development. *Teaching and Teacher Education*, 127, 104095. [[CrossRef](#)]
- Truscott, D., & Barker, K. S. (2020). Developing teacher identities as in situ teacher educators through communities of practice. *The New Educator*, 16(4), 333–351. [[CrossRef](#)]
- Underwood, S. M., & Kararo, A. T. (2021). Design-Based implementation research (DBIR): An approach to propagate a transformed general chemistry curriculum across multiple institutions. *Journal of Chemical Education*, 98(12), 3643–3655. [[CrossRef](#)]
- Wenger, E. (2000). *Communities of practice: Learning, meaning, and identity*. Cambridge University Press.
- Wenger, E., White, N., & Smith, J. D. (2009). *Digital habitats: Stewarding technology for communities*. CPsquare.
- Widyastuti, F., Sajidan, Saputro, S., Sutikno, Fadloli, & Probosari, R. M. (2026). Measuring the effectiveness of the indigenous-based experiential learning model on pre-service science teachers' creative thinking skills. *Jurnal Pendidikan IPA Indonesia*, 15(1). [[CrossRef](#)]
- Williams, H. (2021). *No fear coding: Computational thinking across the K-5 curriculum* (2nd ed.). International Society for Technology in Education.
- Wing, J. M. (2008). Computational thinking and thinking about computing. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical, and Engineering Sciences*, 366(1881), 3717–3725. [[CrossRef](#)] [[PubMed](#)]
- Wu, T.-T., Asmara, A., Huang, Y.-M., & Permata Hapsari, I. (2024). Identification of problem-solving techniques in computational thinking studies: Systematic literature review. *SAGE Open*, 14(2), 21582440241249897. [[CrossRef](#)]

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