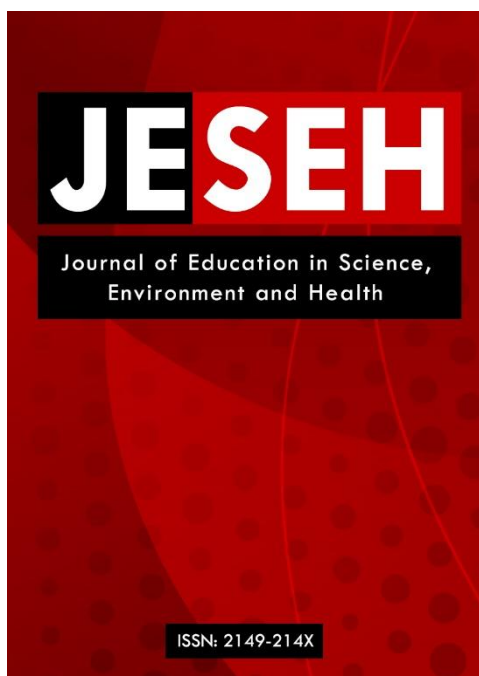




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Investigation of Preservice Science Teachers' STEM Lesson Plan Development and Implementation Process: A Mixed Methods Study

Sumeyra Yilmaz, Bulent Aydogdu

Article Info	Abstract
Article History Published: 01 October 2026 Received: 29 March 2026 Accepted: 10 August 2026 Keywords Integrated STEM Preservice science teachers Lesson plan development Teaching intention STEM attitudes Computational thinking	This mixed methods study examined changes in preservice science teachers' STEM attitudes, integrated STEM teaching intentions, computational thinking (CT) skills, and lesson plan quality across a 16-week STEM lesson planning and implementation process. Participants were 34 third-year preservice science teachers selected through criterion sampling. Over 16 weeks, they developed, revised, and implemented STEM lesson plans in teams, guided by iterative expert feedback. Using an embedded design, quantitative data were collected through the STEAM Attitude Scale, the Integrative STEM Teaching Intention Questionnaire, the CT Scale, and the STEM Integration Curriculum Assessment (STEM-ICA), and qualitative data were gathered through pre- and post-implementation focus group interviews. Findings revealed statistically significant increases in participants' STEM attitudes, integrated STEM teaching intentions, and CT skills. Lesson plan scores increased across the nine STEM-ICA categories, with the clearest gains in context and engineering design. Focus group data showed a comparable pattern but also revealed a divergence in the assessment category, where changes in participants' accounts were not fully reflected in their plans. These results suggest that structured STEM lesson planning and implementation processes can strengthen preservice teachers' preparation for integrated STEM teaching.

Introduction

Interdisciplinary approaches have gained considerable prominence in science education in recent years (Takeuchi et al., 2020). Among these approaches, STEM education proposes treating science, technology, engineering, and mathematics not as separate content areas but as an integrated whole anchored around real-world problems (Moore et al., 2014). This approach fosters innovative thinking by equipping students with essential 21st-century skills such as critical thinking, problem-solving, and collaboration (Chen et al., 2023). Therefore, the integration of STEM has become a critical pillar of national education policies and strategic frameworks (Bybee, 2010; National Research Council [NRC], 2012). Yet despite this policy emphasis, uncertainties remain regarding its practical implementation and instructional design (Falloon et al., 2020; Hilde et al., 2020).

Although theoretical frameworks define the nature of integration, translating these frameworks into classroom practice largely depends on the teacher's interpretation. It is widely accepted that the successful integration of STEM into classrooms depends on teachers' pedagogical knowledge, teaching intentions, and positive attitudes (Aldahmash et al., 2019; Eckman et al., 2016). Research indicates that teachers often encounter significant challenges during this process, which may stem from insufficient professional preparedness and skills required for effective STEM instruction (Guzey et al., 2019; Roehrig et al., 2012). This challenge persists during the preservice stage, as preservice science teachers (PSTs) frequently view distinct disciplines side by side in STEM planning without establishing meaningful connections between them (Spikic et al., 2023). Therefore, teacher education programs need structured processes where PSTs can gain experience in STEM lesson planning and implementation (Ergün & Kıyıcı, 2019; Zhang & Zhu, 2023).

Lesson planning is a primary site of instructional decision-making, and in STEM contexts it requires preservice teachers to coordinate disciplinary content and engineering design within a single instructional sequence. Although STEM lesson planning is widely recommended in teacher education, few studies have examined how designing and implementing such plans influences PSTs' STEM attitudes, integrated STEM teaching intentions, and computational thinking (CT) (Mumcu et al., 2023; Wu et al., 2019). Attitudes and integrated STEM teaching intentions are closely related in shaping future teaching practice (Kurup et al., 2019; Şenyiğit & Serin, 2022). Examining attitudes and integrated STEM teaching intentions within the same instructional process can therefore provide a more complete picture of preservice teachers' development. As one of the prominent components of

integrated STEM in recent years, CT has predominantly been addressed through programming-based activities, whereas less is known about how pedagogical processes such as lesson planning and implementation influence this skill (Zeng et al., 2023).

This study therefore examines changes in PSTs' attitudes toward STEM, integrated STEM teaching intentions, and CT skills across a structured STEM lesson planning and implementation process. It also traces changes in the quality of the lesson plans PSTs produce and examines how PSTs account for their development in pre- and post-implementation focus group interviews. Accordingly, the following research questions were addressed:

1. How do PSTs' STEM attitudes, integrated STEM teaching intentions, and CT skills change over a 16-week STEM lesson planning and implementation process?
2. In what ways does the quality of PSTs' lesson plans change across this process?
3. How do PSTs' accounts of integrated STEM instruction change from pre- to post-implementation focus group interviews?

Conceptual Framework

Integrated STEM Education

STEM education is commonly defined as the purposeful integration of science, technology, engineering, and mathematics (Breiner et al., 2012). Johnson (2013) frames the concept in terms of interdisciplinarity, describing STEM as an instructional approach that integrates science, technology, engineering, and mathematics to foster 21st-century skills. In both accounts, STEM instruction aims to create a holistic learning environment by addressing real-world problems from an interdisciplinary perspective (Holmlund et al., 2018). Because real-world problems naturally involve multiple fields, STEM brings these disciplines together around a core problem (Moore et al., 2014), which helps students connect what they learn in school with their everyday lives (Brophy et al., 2008; Stohlmann et al., 2012).

STEM practices vary depending on how closely disciplines are connected. In the silo approach, subjects are taught separately (Breiner et al., 2012), while in the embedded approach a main discipline is supported by another, though the connection between them often remains implicit. The integrated approach adopted in this study aims to remove the boundaries between disciplines (Wang et al., 2011). Sanders (2009) describes this view as teaching and learning across multiple STEM fields, whereas Moore et al. (2015) emphasize teaching engineering practices alongside science or mathematics through engineering design. Kelley and Knowles (2016) similarly describe integrated STEM as a model in which learning is organized around iterative engineering design and inquiry-based problem solving. Existing frameworks identify contexts, engineering design, student-centered methods, and collaborative learning as its defining features (Stohlmann et al., 2012; Thibaut et al., 2018).

Bringing integrated STEM into the classroom depends on teachers. Research shows that teachers often struggle to integrate subjects outside their own fields (Çolakoğlu & Günay Gökben, 2017). Because this approach requires broad content knowledge, integrated pedagogical skills, and design thinking (Lesseig et al., 2016), developing these competencies during PSTs education has been emphasized in the literature (Sanders, 2009).

CT in STEM Education

The concept of CT was first defined by Wing (2006) as a thought process involving problem solving, system design, and understanding human behavior by drawing on computer science concepts. Aho (2012) describes the concept as formulating problems through computational steps and models. Although there is no consensus in the literature regarding its scope (Brennan & Resnick, 2012), problem analysis, pattern recognition, abstraction, and algorithmic thinking are accepted as core components (International Society for Technology in Education & Computer Science Teachers Association [ISTE & CSTA], 2011). These components are closely related to the development of abstract thinking, logical reasoning, and problem-solving skills (Angeli & Giannakos, 2020).

As CT has evolved from a skill specific to computer science into a part of general education, discussions have focused on how to integrate it with different disciplines. Gülbahar et al. (2019) note that this skill can be fostered from an early age through an interdisciplinary approach. STEM instruction provides a suitable foundation for this integration because it addresses real-world problems in an interdisciplinary manner (Barr et al., 2011; Swaid, 2015). The literature indicates a connection between STEM education and CT (Sun et al., 2021), and Ketelhut et

al. (2020) found that integrating this skill into lessons supports science teaching. For preservice teachers, CT matters both as a personal competency and as a basis for the learning environments they will later design (Yadav et al., 2014). Grover and Pea (2013) describe CT as a set of problem-solving approaches applicable to complex, real-world problems, which suggests that structured STEM lesson design may offer a context in which PSTs engage with these approaches rather than treating them as an isolated technical skill.

However, how this integration should be carried out remains unclear (Li et al., 2020; Sun et al., 2021). A further limitation is that teacher education research on CT has largely focused on information technology teachers, while studies involving teachers from other disciplines remain limited (Blum & Cortina, 2007; Yadav et al., 2014). Yet CT is an expected competency for all teachers and developing it during the preservice period has been emphasized (Yadav et al., 2014). These gaps point to the need for research examining how PSTs' CT skills change throughout teacher preparation.

PSTs' STEM Attitudes and Integrated STEM Teaching Intentions

Affective characteristics such as attitude, interest, and motivation play a crucial role in the learning process (Gömlüksiz, 2003). Attitudes toward STEM encompass individuals' interests, values, and perceptions regarding STEM disciplines (Tseng et al., 2013) and are closely linked to interest in STEM fields (Corlu et al., 2014; Unfried et al., 2015). For PSTs, the importance of attitude is twofold: it affects not only their own learning but also the learning environments they will create in the future. Indeed, students' STEM perceptions and interests have been found to relate to teachers' attitudes toward STEM instruction (Al Salami et al., 2017). The literature shows that PSTs with positive attitudes toward STEM are more likely to adopt interdisciplinary strategies and establish real-world connections (Radloff & Guzey, 2017).

Teaching intention refers to PSTs' inclination to implement integrated STEM in their future classrooms. Lin and Williams (2016) approached this concept as behavioral intention, examining it across five dimensions: knowledge, value, attitude, subjective norm, and perceived behavioral control and behavioral intention. These dimensions correspond closely to the components of the Theory of Planned Behavior, which underscores the link between attitude and intention: attitude is one of the closest predictors of intention (Ajzen, 1991). Evaluating PSTs' STEM attitudes and integrated STEM teaching intentions together therefore provides insight into their future instructional choices (Hacıömeroğlu, 2018).

The literature suggests that both variables can be developed during the preservice period (Kurup et al., 2019; Şenyiğit & Serin, 2022). Teacher development programs have been found to positively affect attitudes toward interdisciplinary teaching (Al Salami et al., 2017), and teaching experiences during preservice education shape preservice teachers' beliefs and attitudes (Cansiz & Cansiz, 2022). How these changes unfold within structured instructional processes, however, remains less clear (Hiğde et al., 2020). These gaps point to the need for research that tracks attitudes and teaching intentions together within the same process.

Developing and Implementing STEM Lesson Plans in Teacher Education

The role of teachers in STEM instruction is not limited to mastering content knowledge; the ability to design and implement lessons also directly affects the quality of teaching (National Academy of Engineering & National Research Council [NAE & NRC], 2014). The STEM training received by PSTs is often content-focused, and how they will integrate STEM into their lessons and manage instruction is not adequately addressed (Corlu, 2014; Srikoom et al., 2018). The separate treatment of disciplines in teacher preparation programs reinforces this pattern, and preservice teachers may graduate without being ready to design integrated STEM instruction (Wu et al., 2021).

Lesson plans serve as both the medium and the observable output of this design process. Different models are proposed in the literature for structuring integrated STEM lesson plans. Bybee (2019) recommends the 5E instructional design for this purpose, and Çiftçi et al. (2022) note that this model facilitates establishing connections among STEM disciplines. Guzey et al. (2016) propose a framework consisting of nine criteria for evaluating STEM lesson plans: a motivating and engaging context, an engineering design challenge, integration of science content, integration of mathematics content, instructional strategies, teamwork, communication, performance and formative assessment, and organization. This framework, operationalized as the STEM Integration Curriculum Assessment (STEM-ICA), allows lesson plan quality to be monitored through concrete criteria and was used in the present study.

Lesson plan development is not a one-time preparation but a cyclical process involving design and revision. Effective STEM lesson planning requires structuring activities that incorporate inquiry, engineering design, and real-world connections (Estapa & Tank, 2017). Revising plans based on expert feedback and subsequently implementing them offers PSTs a setting in which the integrated approach is experienced rather than only described. Implementations carried out in a peer environment enable them to recognize the difficulties they encounter while putting STEM principles into practice (Ryu et al., 2019). The literature also includes studies associating such iterative design and implementation cycles with PSTs' self-efficacy perceptions and STEM teaching intentions (Dökme & Koyunlu Ünlü, 2024; Ribeirinha & Correia, 2025).

Method

Research Design

This study employed an embedded mixed methods design (Creswell & Plano Clark, 2011) to examine changes in PSTs' STEM attitudes, integrated STEM teaching intentions, CT skills, and lesson plan quality across a 16-week STEM lesson planning and implementation process. Quantitative data were collected through pretest and posttest scales and rubric scores for participants' lesson plans. Qualitative data were obtained from pre- and post-implementation focus group interviews, which were coded using the categories of the STEM-ICA. In this design, the qualitative strand was embedded within the quantitative strand and served to clarify the patterns observed in the measures rather than to test them independently. As the study used a one-group pretest-posttest design, causal inferences cannot be drawn, and the findings are reported as changes observed across the process.

Participants

An a priori power analysis was conducted using G*Power (Faul et al., 2007) to determine the required sample size for a repeated measure MANOVA with within-subjects factors. Assuming a medium effect size ($f = .25$), $\alpha = .05$, and power = .80, with two measurement points and a correlation of .50 among repeated measures, the analysis indicated a minimum of 34 participants. The participants were 34 third-year PSTs (27 women, 7 men) enrolled at a state university in Türkiye. The study group was formed using criterion sampling, a purposeful sampling method involving the selection of individuals who meet predetermined criteria relevant to the research problem (Patton, 2002). The primary criterion was the successful completion of the courses "Approaches to Science Learning and Teaching" and "Science Teaching Programs," as completion of these courses indicates that participants had acquired foundational pedagogical knowledge of the current science curriculum, instructional methods, and classroom application. All 34 participants completed both pre- and post-measures, with no attrition over the 16-week process. To ensure confidentiality, participants were coded as P1 through P34.

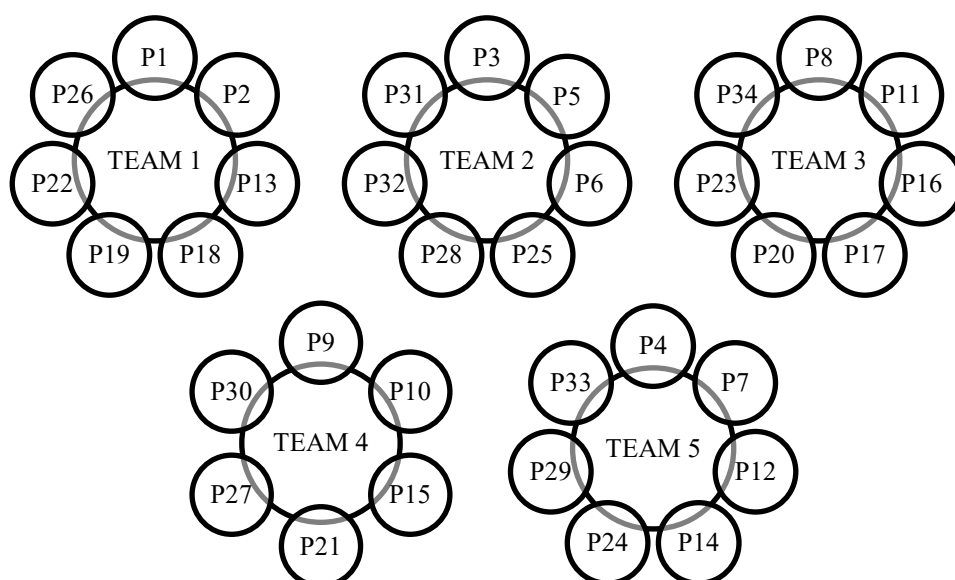


Figure 1. Distribution of participants across teams

Research indicates that collaborative teamwork among teachers often yields more effective instructional outcomes than individual efforts (Hong, 2014; van de Pol et al., 2012). Participants were therefore organized by the researchers into five heterogeneous teams, balanced in terms of academic achievement and gender. This structure was maintained throughout the 16-week process to support peer learning and collective lesson design. The teams are presented in Figure 1.

Data Collection Tools

STEAM Attitude Scale

To determine changes in participants' STEM attitudes, the STEAM Attitude Scale, developed by Kim and Bolger (2017) and adapted into Turkish by Çevik and Ata (2019), was used. Both the original and the adaptation studies were conducted with preservice teachers. The scale consists of 25 items across three dimensions: interest, perceived ability, and value. The three dimensions account for 54.91% of the total variance. Items are rated on a four-point Likert-type scale, with total scores ranging from 25 to 100. The scale includes 11 reverse-scored items. In the adaptation study, Cronbach's alpha coefficients were .90 for interest, .83 for perceived ability, and .85 for value. For the present sample, Cronbach's alpha for the total scale was .95 at pretest and .89 at posttest.

Integrative STEM Teaching Intention Questionnaire

To examine changes in participants' intentions toward integrated STEM instruction, the Integrative STEM Teaching Intention Questionnaire, developed by Lin and Williams (2016) and adapted into Turkish by Hacıömeroğlu and Bulut (2016), was used. Both the original and the adaptation studies were conducted with preservice teachers. The scale consists of 31 items rated on a seven-point Likert-type scale, across five dimensions: knowledge, value, attitude, subjective norm, and perceived behavioral control and behavioral intention. The five dimensions account for 63.09% of the total variance. In the adaptation study, the Cronbach's alpha coefficient for the total scale was .94. For the present sample, Cronbach's alpha for the total scale was .98 at pretest and .96 at posttest.

Computational Thinking Scales

To determine changes in participants' CT skills, the CT Scales, developed by Korkmaz et al. (2017), was used. The scale was developed with university students in Türkiye. It consists of 29 items, six of which are reverse-scored, rated on a five-point Likert-type scale, with total scores ranging from 29 to 145. The scale comprises five dimensions: creativity, algorithmic thinking, cooperativity, critical thinking, and problem solving, and accounts for 56.12% of the total variance. In the original study, Cronbach's alpha coefficients ranged from .73 to .87 across the dimensions. For the present sample, Cronbach's alpha for the total scale was .97 at pretest and .92 at posttest.

STEM Integration Curriculum Assessment (STEM-ICA)

To examine the STEM lesson plans that participants prepared before and after the process, the STEM-ICA (Guzey et al., 2016) was used. The tool aligns with the STEM integration framework proposed by Moore et al. (2014), and its content validity was established through expert review. It consists of nine categories: motivating and engaging context, engineering design, integration of science content, integration of mathematics content, instructional strategies, teamwork, communication, assessment, and organization. Each category is rated on a five-point scale from 0 to 4 (0 = not present, 1 = weak, 2 = adequate, 3 = good, 4 = excellent), yielding total scores ranging from 0 to 36. Each category includes guiding questions, and reviewers record the evidence supporting each rating.

Semi-Structured Focus Group Interview Form

A semi-structured focus group interview form was developed by the researchers to examine changes in participants' accounts of integrated STEM instruction across the STEM-ICA categories and to clarify the patterns observed in the quantitative measures. Focus groups were chosen because they provide more detailed insights into the research problem (Krueger & Casey, 2014). An initial set of 10 questions was prepared in line with the research

questions and reviewed by four experts (two in science education and STEM, two in measurement and evaluation). The questions were revised accordingly, organized into sections, and supplemented with probes. A pilot study was then conducted with a group of six preservice teachers, as it is recommended that pilot focus groups be similar in size to the actual groups (Yıldırım & Şimşek, 2016). The pilot study confirmed that the questions were clear and appropriate for their purpose.

The questions were structured around the categories of the STEM-ICA, addressing motivating and engaging contexts, the engineering design challenge, the integration of science and mathematics content, instructional strategies, teamwork, communication, and assessment. Interviews were conducted twice with each of the five teams, before and after the process, yielding a total of 10 focus group interviews. All interviews were conducted in Turkish, the participants' native language. The quotations presented in this article were translated into English by a professional translator, and the translations were reviewed by a bilingual expert in science education to ensure that the original meaning was preserved.

Pilot Implementation Process

A pilot implementation was conducted with 32 third-year PSTs during the spring semester of the 2021–2022 academic year. The pilot ran for 12 weeks, two hours per week, with participants working in four heterogeneous teams of eight. The first weeks covered theoretical content on integrated STEM and lesson plan development. Participants then developed STEM lesson plans in their teams, and each week one team implemented its plan in a simulated classroom environment with peers acting as students. Throughout the pilot, the researchers conducted informal discussions with participants and observed the process.

Observations, participant feedback, and expert opinions led to several revisions for the main study. The duration was extended from 12 to 16 weeks at five hours per week, and the time allocated for each team's classroom implementation was extended from one week to two. Team size was reduced, as teams of eight created difficulties in dividing tasks. The Computational Thinking Scale was added, the informal discussions were replaced with semi-structured focus group interviews conducted before and after the process, and the STEM-ICA was adopted to examine changes in lesson plan quality.

Main Implementation Process

The main implementation was conducted during the fall semester of the 2022–2023 academic year within the scope of the Science Teaching course. The process spanned 16 weeks, totaling 80 instructional hours (five hours per week). This duration was determined based on literature suggesting that teacher professional development programs should involve at least 80 hours to support changes in teachers' attitudes, beliefs, and willingness to implement new pedagogical approaches (Çorlu, 2017; Supovitz & Turner, 2000).

Weeks 1–3: Preparation and Theoretical Foundation

In the first week, participants were informed about the research, consent forms were obtained, teams were formed, and pretests and the initial focus group interviews were administered. During the second and third weeks, the researcher covered theoretical content on STEM, STEM integration, science education, the engineering design process, entrepreneurship, and STEM lesson plan development. Sample lesson plans were examined. An information technologies specialist then delivered a session on the role of technology and coding in STEM instruction, followed by coding activities. By the end of the third week, each team was asked to develop a knowledge-based real-life problem aligned with the objectives in the national science curriculum.

Weeks 4–5: Design and Expert Feedback

In the fourth week, teams presented their problem scenarios and the learning outcomes they had selected. Three experts (one in STEM education, one in science education, and one in curriculum development) provided feedback and suggested revisions. Teams then developed their STEM lesson plans according to the 5E instructional model. In the fifth week, the completed plans were presented to the same panel, and teams revised them once more in line with the feedback received.

Weeks 6–16: Implementation of the Lesson Plans

Each team implemented its lesson plan over two weeks, totaling 10 instructional hours. During these sessions, the implementing team acted as teachers while the remaining teams participated as students, working in groups to develop solutions to the problem scenario. Teams moved through the 5E phases: the lesson opened with the knowledge-based real-life problem, students discussed and identified the problem, presented their proposed designs, built and tested prototypes, and finally marketed and evaluated their products using a predetermined rubric. The three experts observed these sessions and provided evaluations of the process. In the final week, the post-implementation focus group interviews and posttests were administered.

STEM Lesson Plans and Prototype Designs

Each team developed two versions of its STEM lesson plan: an initial version and a revised version prepared following expert feedback. Teams selected the middle school science learning outcomes for their plans and determined the duration of the activities. This yielded a total of 10 lesson plans, two from each of the five teams, which were analyzed using the STEM-ICA. The themes of the lesson plans and their implementation schedule are presented in Table 1. The prototypes produced during the implementation sessions are presented in Figure 2.

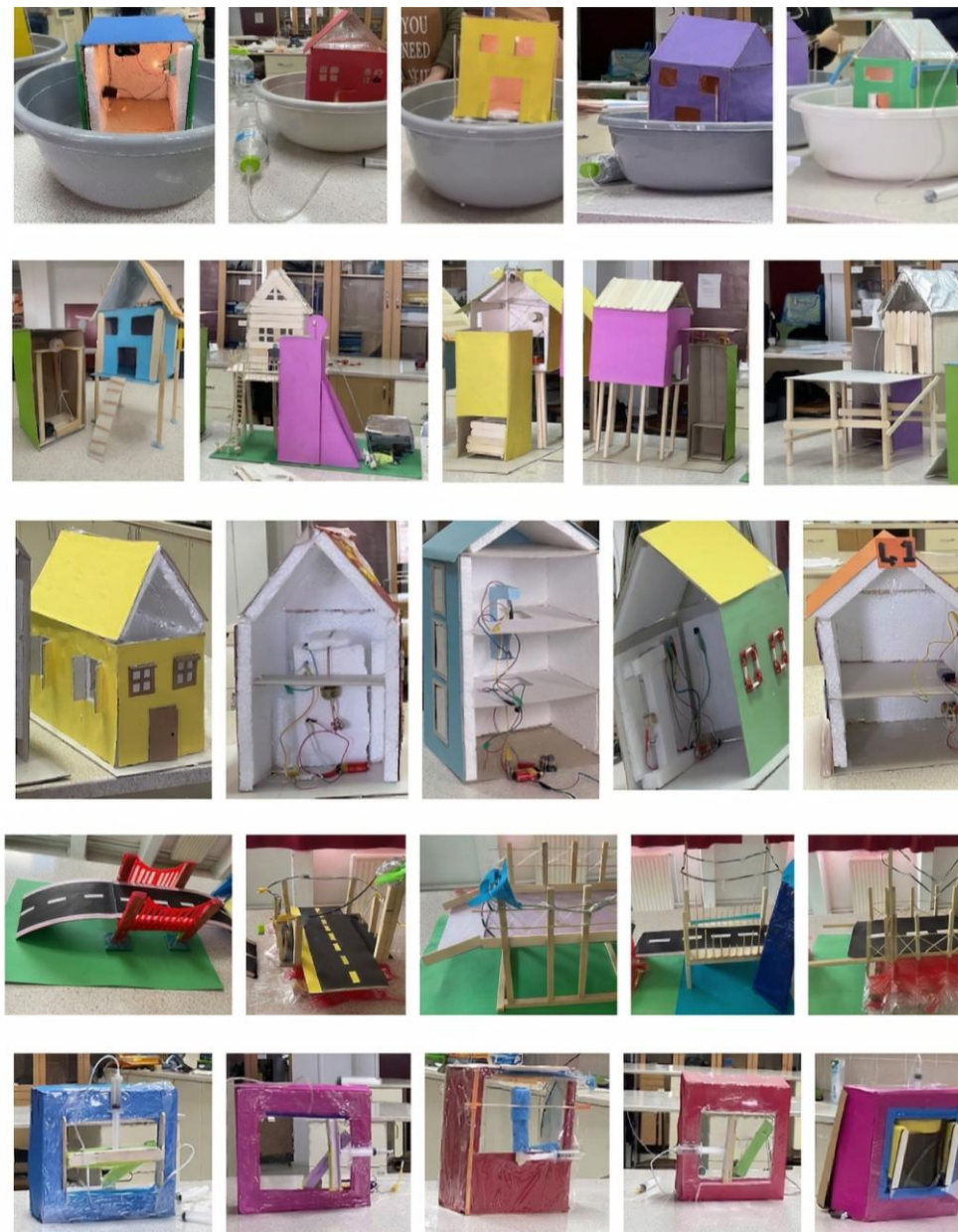


Figure 2. Prototypes developed by teams

Table 1. Implementation schedule and STEM lesson plan themes

Team	Lesson plan theme	Weeks
1	Flood-Resistant Hut	6–7
2	Elevated Granary with a Lift	8–9
3	Earthquake-Resilient Housing Project	10–11
4	Eco-Friendly Bridge	12–13
5	Self-Cleaning Window	14–15

Data Analysis

The quantitative and qualitative data were analyzed separately and then brought together in the interpretation of the findings. Prior to the quantitative analysis, the assumptions of the multivariate analysis of variance (MANOVA) were examined. Normality was assessed using the Shapiro-Wilk test together with skewness and kurtosis values, and the correlations among the dependent variables were checked for multicollinearity. The assumptions were met. A one-way repeated measures MANOVA was conducted to examine the differences between pretest and posttest scores across the three scales simultaneously. In this multivariate model, time (pretest and posttest) was defined as the within-subjects factor, and the scores from the three scales (Integrative STEM Teaching Intention Questionnaire, STEAM Attitude Scale, and Computational Thinking Scale) served as the set of dependent variables. Wilks's Lambda was used as the multivariate test statistic, and partial eta squared values were calculated to report effect sizes.

The STEM lesson plans developed by the teams were evaluated using the STEM-ICA (Guzey et al., 2016) across its nine categories: motivating and engaging context, engineering design challenge, integration of science content, integration of mathematics content, instructional strategies, teamwork, communication, performance and formative assessment, and organization. Each category was scored from 0 to 4. Two researchers independently scored the 10 lesson plans and reached consensus on the final scores through discussion. The plans were coded and presented to the raters in random order, with no indication of whether a plan was an initial or a revised version, so that scoring was not influenced by expectations of improvement. Because the plans were developed collaboratively by five teams, the STEM-ICA scores were examined descriptively rather than through inferential testing. The focus group interviews were audio-recorded, transcribed, and analyzed through descriptive and content analysis (Yıldırım & Şimşek, 2016). Two researchers coded the transcripts independently. The post-implementation transcripts were first coded deductively using the nine categories of the STEM-ICA, and participants' explanations of the revisions they had made to their lesson plans were then coded inductively to identify types of revision. Interrater agreement was calculated using the formula $[\text{agreement} / (\text{agreement} + \text{disagreement}) \times 100]$ (Miles & Huberman, 1994), yielding 90% agreement. The resulting codes and categories are presented in tables and supported by direct quotations from the participants.

Validity, Reliability, and Trustworthiness

For the quantitative instruments, validity relies on the original development and adaptation studies of each scale, and reliability coefficients were recalculated for the present sample and are reported above. All scales were administered under the same conditions at both measurement points. The lesson plans were scored using the STEM-ICA (Guzey et al., 2016), a rubric whose content validity was established through expert review in its original study. Two researchers scored the plans independently and reached a consensus on final scores through discussion. To prevent scoring bias from expectations of improvement, the plans were coded and presented to the raters in random order, concealing whether a given plan was an initial or a revised version.

For the qualitative component, trustworthiness was addressed through the criteria of credibility, transferability, dependability, and confirmability (Lincoln & Guba, 1985). Credibility was supported by triangulating focus group interviews with lesson plan ratings across the 16-week process, and interview transcripts were returned to participants for confirmation prior to analysis. Transferability was supported by providing detailed descriptions of the participants, the instructional setting, and the process. Dependability and confirmability were maintained through an audit trail comprising audio recordings, transcripts, and scoring sheets. Two researchers coded the transcripts independently, yielding an interrater agreement of 90%.

Several measures were also taken to reduce potential bias: participants were informed that their responses would not affect course grades, lesson plans were scored blind to version, and three external experts observed the implementation sessions and provided feedback on the process.

Findings

Quantitative Results

A one-way repeated measures MANOVA was conducted to examine changes across three combined dependent variables over the 16-week process: Integrative STEM Teaching Intention, STEAM Attitude, and CT. Preliminary assumption testing indicated that the data met the requirements for multivariate analysis. Since the within-subjects factor (time) consisted of only two levels, Mauchly's test of sphericity was inherently satisfied ($W = 1.00$) for all measures.

The multivariate results revealed a statistically significant main effect for time, Wilks's $\Lambda = .601$, $F(3, 31) = 6.862$, $p = .001$, partial $\eta^2 = .399$. This indicates that participants' scores across the three constructs changed significantly when considered simultaneously. To examine the nature of this change, follow-up univariate repeated measures ANOVAs were conducted for each dependent variable. A Bonferroni correction was applied across the three comparisons, yielding an adjusted alpha of .017. All three results remained significant under this criterion.

Integrative STEM Teaching Intention: Scores increased from pretest ($M = 183.97$, $SD = 30.20$) to posttest ($M = 201.68$, $SD = 18.36$), $F(1, 33) = 10.189$, $p = .003$, partial $\eta^2 = .236$.

STEAM Attitude: Scores increased from pretest ($M = 75.26$, $SD = 13.36$) to posttest ($M = 83.94$, $SD = 9.56$), $F(1, 33) = 18.420$, $p < .001$, partial $\eta^2 = .358$.

CT: Scores increased from pretest ($M = 112.65$, $SD = 18.42$) to posttest ($M = 122.44$, $SD = 15.00$), $F(1, 33) = 9.255$, $p = .005$, partial $\eta^2 = .219$.

Scores on all three measures increased over the process, with the largest effect size observed for STEAM Attitude (partial $\eta^2 = .358$). Descriptive statistics and univariate results are summarized in Table 2.

Table 2. Descriptive statistics and univariate ANOVA results

Measure	Pretest <i>M</i> (<i>SD</i>)	Posttest <i>M</i> (<i>SD</i>)	<i>F</i> (1,33)	<i>p</i>	Partial η^2
Integrative STEM Teaching Intention	183.97 (30.20)	201.68 (18.36)	10.189	.003	.236
STEAM Attitude	75.26 (13.36)	83.94 (9.56)	18.420	<.001	.358
CT	112.65 (18.42)	122.44 (15.00)	9.255	.005	.219

Changes in Lesson Plan Quality

During the process, PSTs worked in collaborative teams to design and revise their STEM lesson plans, which went through a development cycle involving expert feedback and classroom implementation. A total of ten lesson plans, an initial and a final version from each of the five teams, were evaluated using the STEM-ICA. The quality of the lesson plans was examined through the total scores derived from the STEM-ICA. The total score range (0–36) was divided into five levels corresponding to the item-level descriptors of the original rubric: 0–8 (none), 9–15 (weak), 16–22 (satisfactory), 23–29 (good), and 30–36 (excellent). These levels are summarized in Table 3 and are used only to aid interpretation.

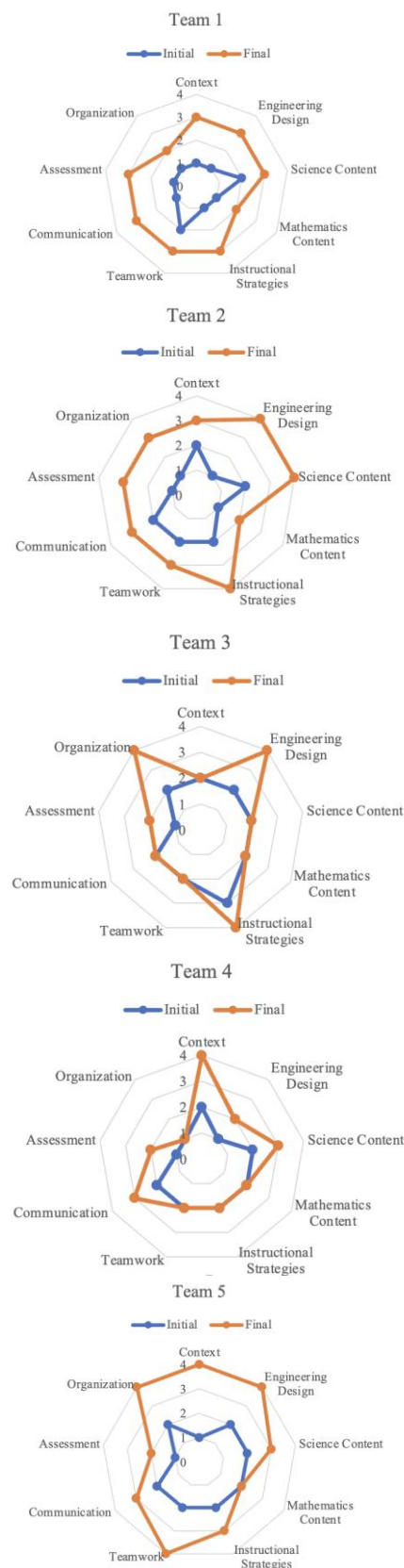
Table 3. Evaluation levels for the STEM-ICA total scores

Score range	Level
0–8	None
9–15	Weak
16–22	Satisfactory
23–29	Good
30–36	Excellent

A comparison of the initial and final total scores obtained by the five teams is presented in Table 4. Scores increased for every team. The initial plans had a mean score of 14.8, corresponding to the weak level, whereas the final versions had a mean score of 25.6, corresponding to the good level. Four of the five teams reached the good level in their final version, and one team moved from weak to satisfactory.

Table 4. Initial and final STEM-ICA total scores by team

Phase	Team 1	Team 2	Team 3	Team 4	Team 5	Mean
Initial	11 (Weak)	14 (Weak)	18 (Satisfactory)	15 (Weak)	16 (Satisfactory)	14.8 (Weak)
Final	25 (Good)	29 (Good)	24 (Good)	21 (Satisfactory)	29 (Good)	25.6 (Good)



Scores increased in all categories, remaining lowest in mathematics content and organization.

Scores increased in all categories, remaining lowest in mathematics content.

Scores increased in engineering design, instructional strategies, assessment, and organization, and remained unchanged in the other five categories.

Scores increased in six categories and remained unchanged in instructional strategies, teamwork, and organization.

Scores increased in eight categories and remained unchanged in mathematics content.

Figure 3. Initial and final STEM-ICA category scores by team

Based on the total scores presented in Table 4, the pedagogical progress of each team was further analyzed across the nine specific categories of the STEM-ICA rubric. To provide a detailed representation of this development, the qualitative overviews and comparative radar charts for each team are presented in Table 5. These charts illustrate the shifts in scores between the initial and final versions of the lesson plans across categories such as Engineering Design Challenge, Integration of Science Content, and Instructional Strategies. The scores were also examined across the nine STEM-ICA categories. Category-level comparisons of the initial and final versions for each team are presented in Figure 3.

Qualitative Results

Changes in PSTs' Accounts of Integrated STEM

Semi-structured focus group interviews were conducted before and after the process to examine how participants described integrated STEM instruction and to clarify the changes observed in the lesson plan scores. The interview data were coded using the nine categories of the STEM-ICA. This allowed a comparison of how participants' accounts of elements such as teamwork, the engineering design challenge, and science and mathematics integration changed over the process. The coded accounts and category summaries are presented in Table 5.

Table 5. Pre- and post-implementation focus group findings by category

Category	Summary of findings	Pre-interview quotations	Post-interview quotations
Motivating and Engaging Contexts	In the initial interviews, participants described context in terms of sparking curiosity and connecting to daily life. In the final interviews, they also referred to societal issues, environmental problems, current events, and the engineering design process.	<i>"If there is a context that students can encounter in their daily lives, students' interest increases. More students speak up in class because daily events catch their attention."</i> (P8) <i>"If the context increases students' curiosity, it can be effective."</i> (P29)	<i>"If the context includes current events, for example, a context related to vaccines and viruses during a pandemic can motivate students more."</i> (P20) <i>"Topics such as environmental pollution, environmental problems, and a globalizing world capture students' interest more."</i> (P25)
Engineering Design Challenge	In the initial interviews, participants referred to basic design and product development. In the final interviews, they also mentioned prototyping, testing, cost and material considerations, and engineering technologies.	<i>"Depending on the scope of the topic, students experience engineering design during the product creation stage."</i> (P7) <i>"Students design products in class. Engineering is an important topic at this stage...."</i> (P16)	<i>"Students develop prototypes and test their products. They actively use engineering design processes."</i> (P3) <i>"In STEM, within the framework of the scenario and its constraints, students aim to produce the best design by determining cost and materials. Of course, completing it in the shortest time also matters...."</i> (P6)
Integration of Science Content	In the initial interviews, participants emphasized scientific process skills. In the final interviews, they also mentioned the nature of science, access to scientific knowledge, and socioscientific issues.	<i>"Individual experiments can be included in STEM practices. Students perform experiments."</i> (P15) <i>"Data collection, recording, and developing hypotheses... scientific processes take place in most parts of STEM teaching."</i> (P25)	<i>"The nature of science has an important place in STEM teaching. What is scientific knowledge and how is it reached? How does one become scientifically literate?"</i> (P4) <i>"Social issues are also used to develop awareness in students. For example, socioscientific issues... These controversial issues act as a bridge between science and STEM integration."</i> (P16)
Integration of Mathematics Content	In the initial interviews, participants referred to measurement and calculation in general	<i>"Mathematics is integrated with STEM teaching through mathematical</i>	<i>"For example, when calculating a budget for a product, calculating percentages, or calculating time and averages while testing, basic</i>

	terms. In the final interviews, they made similar references but drew their examples from their own implementations, such as budgeting and calculating averages. In the initial interviews, participants mentioned project- and problem-based learning along with direct instruction. In the final interviews, direct instruction was no longer mentioned, and participants also referred to case-based learning, inquiry, discovery, and discussion. In the initial interviews, participants referred to collaboration and individual responsibility. In the final interviews, they also mentioned the teacher's role in guiding teams, the need for a safe learning environment, and the use of discussion techniques.	operations and calculations." (P19) "It incorporates concepts such as slope, perimeter and area calculation, and length measurement within STEM practices." (P25)	mathematical concepts and calculations play an important role." (P16) "Problems encountered while testing the prototype are solved with the help of mathematical calculations." (P30)
Instructional Strategies		"Students practicing more together, that is, cooperative learning, can be used." (P18) "Direct instruction is useful for the teacher in STEM teaching." (P31)	"The scenarios presented are reminiscent of the case study method. The scenarios given to students are actually like a case study... A problem that occurs in real life is solved in the STEM practice...." (P12) "Conducting research becomes necessary within the STEM process. Therefore, it closely resembles the inquiry-based learning approach." (P26)
Teamwork		"Activities that support students' collaboration should be included." (P11) "Every student needs to undertake both group and individual responsibilities." (P14)	"If teachers guide students during the teamwork process, successful work can emerge. The teacher should also provide an atmosphere of respect and trust throughout the work, so that students feel safe in the team and can focus on the work." (P3) "Different discussion techniques such as buzz groups keep teamwork dynamic in STEM practices." (P20)
Communication	In the initial interviews, participants referred to visual and oral communication. In the final interviews, they also mentioned written forms of communication and the presentation of design solutions.	"Communication can also be supported through visual tools such as animations in STEM practices." (P9) "...students making presentations in STEM makes them active in the classroom and positively affects communication." (P30)	"Delivering the scenarios given to students in writing, like a letter, can be one of the important stages in communication." (P8) "When we include STEM practices in lessons, a spokesperson can be chosen from each group to prevent communication from being disrupted and to maintain order. It helps intra-group and inter-group interaction run better." (P5)
Performance and Formative Assessment	In the initial interviews, participants referred to both traditional and process-oriented assessment. In the final interviews, they no longer mentioned traditional tools and emphasized rubrics, portfolios, and performance tasks.	"Fill-in-the-blank and true-false questions are used for assessment aligned with the learning objective." (P21) "If STEM practices are carried out in science classes, multiple-choice tests can be used for assessment, or students can prepare a portfolio." (P23)	"Assessing students by examining their portfolios helps STEM teaching reach its purpose, because STEM also values the process, not just the student's final achievement." (P8) "Assessing the process is beneficial for STEM... For example, we can measure the process through performance tasks and projects. How successful the practice was should be examined." (P20)

Following the classroom implementation of the STEM lesson plans, all teams engaged in a reflective revision process based on the practical challenges encountered during instruction. Table 6 presents the specific types of instructional adjustments made by each team. The analysis shows that all teams revised the constraints within their plans to better align with classroom realities. Regarding the real-world problem scenarios, revisions were made by Teams 1, 2, and 5, while Teams 3 and 4 maintained their initial scenarios. Additionally, most teams focused on rubric revisions and the clear writing of lesson plan stages to enhance the overall quality of their instructional designs. These adjustments demonstrate an increased understanding of classroom dynamics and the practical necessities of integrated STEM teaching.

Table 6. Post-implementation STEM lesson plan revisions

Type of Revision	Team 1	Team 2	Team 3	Team 4	Team 5
Reviewing Learning Outcomes	✓	✓			
Integrating STEM Disciplines	✓		✓		
Adjustment of Real-World Problem	✓	✓			✓
Revising Constraints	✓	✓	✓	✓	✓
Adding a Material Price List		✓	✓		
Revising Activities		✓	✓		
Adjusting Time	✓		✓		
Clarifying the Wording of the Lesson Plan	✓	✓			
Revising Lesson Plan Stages	✓				✓
Revising the Rubric	✓	✓		✓	✓

Participants' explanations illustrate the reasons behind these revisions:

We changed the lighting level item in the rubric for the windmill system to "level of illumination." We decided not to explicitly emphasize the design product by referring to it as a windmill. We expected students to identify the problem and develop their designs with this problem in mind. (P30, Team 4)

When we implemented STEM in the classroom, we realized that we hadn't addressed many areas in our lesson plan. So, we reorganized the stages of the lesson plan and addressed them in more detail. (P3, Team 2)

We added the restriction "Systems should be positioned taking into account the river current (on the right side)" because the river current was unknown, resulting in deficiencies in bridge construction. (P9, Team 4)

Discussion

This study examined the changes observed in PSTs' STEM attitudes, integrated STEM teaching intentions, CT skills, and the quality of their lesson plans throughout a 16-week STEM lesson planning and implementation process. The findings are discussed along with their implications below.

Attitudes Toward STEM

PSTs' STEM attitude scores showed a significant increase in favor of the posttest. This result aligns with findings from similar processes conducted with preservice teachers (Adams et al., 2014; Deniz Çeliker, 2020; Hiğde, 2022; Kim et al., 2015; Kim & Bolger, 2017; Yip, 2020). After drafting their lesson plans, participants implemented them in an environment where peers acted as students, and they had the opportunity to revise their plans afterward. The increase in attitude scores may be related to these two components. Kartal and Taşdemir (2021) also found higher attitude scores among preservice teachers with STEM-focused internship experience. Taken together, these findings suggest that the change in attitudes may be linked to the opportunity to put STEM into practice. In contrast, Bulut et al. (2022) found that the lesson plan development process did not change attitudes among science teachers enrolled in a graduate program. This difference may be related to the characteristics of that participant group and to the fact that the lesson plans were not implemented in a classroom.

Integrated STEM Teaching Intentions

A significant increase was also observed in integrated STEM teaching intention scores. This result is consistent with Hiçde (2022), who reported significant increases in both attitudes and teaching intentions in a similar process. Within the framework of the Theory of Planned Behavior, intention is a construct fueled by subjective norms and perceived behavioral control, alongside attitude (Ajzen, 1991). All three sources appear to have been engaged during this process. Participants worked in teams for 16 weeks, implemented their plans in front of peers, and received iterative feedback from a three-member expert panel. Luehmann (2007) similarly states that teachers need practical teaching experience alongside theoretical knowledge to feel competent in STEM instruction. The literature indicates that research on preservice teachers' teaching intentions has largely been conducted using survey designs, while process-based studies remain limited (Koçak et al., 2019). This study contributes to this gap by tracking changes in intention throughout a structured process.

Computational Thinking Skills

The increase in CT scores can be associated with the cognitive processes engaged during the process. Participants formulated a knowledge-based life problem, transformed this problem into a solvable design task, and structured the lesson progressively according to the 5E model. Breaking down a problem into teachable steps suggests that lesson planning shares common ground with CT. This finding is valuable as it indicates that CT can be developed through pedagogical design processes, not only through programming activities. Considering that teacher education research on this skill has largely concentrated on information technology teachers (Blum & Cortina, 2007; Yadav et al., 2014), this result obtained with PSTs contributes to the literature in this respect. Juškevičienė et al. (2021) also state that instructional processes embedding CT into a STEM context can be functional in developing this skill.

Changes in Lesson Plan Quality

Lesson plan scores increased across all five teams. While the average of the initial plans was 14.8 (weak level), the average of the final plans rose to 25.6 (good level). This increase is consistent with Bozkurt Altan and Ucuncuoglu (2019), who reported development in PSTs' lesson plans through a similar process. Below, this change is discussed at the category level alongside focus group data.

Context and Engineering Design

The most pronounced change was observed in these two categories. In pre-interviews, participants defined context at the level of sparking curiosity and connecting to daily life, whereas in post-interviews they referenced socioscientific issues, environmental problems, and current events. Engineering design was reduced to producing a tangible product in pre-interviews, while stages such as prototype development, testing, and cost and material constraints entered their definitions in post-interviews.

This change can be related to classroom implementation. Participants' post-implementation revision explanations support this interpretation. All teams revised constraints in their plans; one team added a constraint regarding river current, while another refrained from naming the product directly to let students define the problem. Capobianco and Rupp (2014) similarly found that teachers failed to adequately integrate engineering design in their first implementation but succeeded in the second. This result diverges from Burton et al. (2022), where all participants emphasized the importance of real-world context yet only two of six lesson plans included it. The difference may stem from the structure of the two processes, as participants in that study observed and planned STEM lessons but did not implement them.

A limitation also emerged in this category. Technology and engineering learning objectives were occasionally used interchangeably. Kim and Bolger (2017) reported a similar confusion. This suggests that preservice teachers can use the engineering design process functionally but struggle to distinguish the boundaries of the discipline conceptually.

Science Integration and Mathematics Integration

While the integration of science content reached a good level, mathematics integration remained the category with the lowest average, and no team exceeded the satisfactory level. Focus group data support this result; statements

regarding mathematics remained largely similar between pre- and post-interviews, becoming richer only at the level of examples. At first glance, this result seems attributable to participants' content expertise being in science; Kim et al. (2015) similarly linked a comparable finding to a lack of knowledge and interest in mathematics. However, these same participants successfully established integration in science content. The result is therefore more likely related to command over the mathematics curriculum than to a general lack of integration skills. Indeed, in the lesson plans, mathematics was used at the level of measurement and calculation to support engineering design, omitting higher-order learning objectives such as data processing and interpretation. Estapa and Tank (2017) reported a similar pattern. This result also offers a practical implication. In STEM processes conducted with PSTs, expert support can be sought from the mathematics department, or collaboration can be planned with preservice mathematics teachers.

Instructional Strategies

Statements regarding direct instruction found in pre-interviews disappeared in post-interviews, replaced by student-centered approaches such as inquiry-based learning, discovery learning, and case studies. Emphasis on the 5E learning model also increased in post-interviews. This change aligns with studies stating that STEM instruction requires inquiry and project-based approaches (Breiner et al., 2012) and with findings indicating that the 5E model facilitates interdisciplinary connections (Çiftçi et al., 2022). Lesson plan scores also support this tendency, and Spikic et al. (2023) found that preservice teachers succeeded in designing instructional strategies in integrated STEM implementations. The most likely explanation for this change is that participants experienced the role of students during their peers' implementations. Experiencing teacher-centered lecturing from the student's perspective may have accelerated their move away from this approach. This interpretation indicates that the dual-role structure of the process provided not only teaching experience but also a student perspective.

Assessment

In post-interviews, participants omitted traditional assessment tools entirely and emphasized process-oriented tools such as portfolios and performance tasks. However, final lesson plans still included multiple-choice and short-answer questions; although the category average rose from 1 in the initial plans to 2.4, no team reached the highest level. This shows that change at the discourse level did not fully translate into the lesson plans. Participants could express the necessity of process-oriented assessment but struggled to turn it into a plan. Wieselmann et al. (2022) also found that formative tools are underutilized in preservice STEM education. These findings indicate that addressing the assessment dimension at the level of awareness alone is insufficient.

Teamwork, Communication, and Organization

In the teamwork category, all teams scored 2 in their initial plans, reaching an average of 2.8 in the final plans, with one team reaching the highest level. In the communication category, participants gave detailed accounts in the final interviews, referring to written forms and to ways of organizing interaction within and between teams. These considerations appeared only to a limited extent in the lesson plans, mirroring the divergence observed in the assessment category. Guzey et al. (2016) also found that communication was not treated as a focal point in STEM designs prepared by teachers. In the organization category, variation between teams was greatest; one team remained at the weak level while two teams received the highest scores. The communication and organization categories share a common feature: they are not visible components of a lesson plan. While context and the design task sit at the core of the plan, communication patterns and lesson flow belong to its implicit structure.

Conclusion

When the findings are evaluated collectively, the observed change appears to stem from the combination of three features rather than from a single component of the process: turning plans into actual implementations, having the opportunity to revise after implementation, and receiving iterative expert feedback. As the qualitative data showed, the most concrete progress occurred at points where preservice teachers addressed difficulties they encountered during implementation. This points to the importance of structuring lesson planning not as a writing task but as a cycle involving implementation and revision. The same findings also demonstrate the boundaries of the process. Development remained limited in the mathematics integration and assessment categories, and the communication dimension was insufficiently reflected in the lesson plans. A structured lesson planning process

does not appear to develop every component equally, and certain categories may need to be targeted separately and explicitly. The discourse-product divergence emerging in the assessment and communication categories also offers a methodological implication. The development participants expressed and the development seen in the plans they produced do not always overlap; a similar divergence was reported by Burton et al. (2022). This indicates that relying solely on scale or interview data in teacher education research can make development appear stronger than it is, and that product-based data balances this picture.

Limitations and Future Directions

This study examined the changes observed in PSTs' STEM attitudes, integrated STEM teaching intentions, computational thinking skills, and the quality of their lesson plans throughout a 16-week STEM lesson planning and implementation process. The findings should be interpreted in light of several methodological and contextual limitations.

The study relied on a single-group pretest-posttest design without a control or comparison group. Because participants took concurrent courses, continued to develop professionally over the semester, and completed the same instruments twice, the interpretations offered in the discussion represent plausible accounts rather than causal claims. Future research employing comparison groups and isolating specific components of the process could help determine which component contributes to which outcome.

The sample was restricted to 34 PSTs at a single state university in Türkiye, limiting the generalizability of the findings to other institutions, programs, or national contexts. Replications across diverse settings would help establish transferability. Furthermore, the participants' science-focused background may have contributed to the lower integration scores observed in mathematics; future designs incorporating interdisciplinary cohorts, such as pairing preservice science and mathematics teachers, could address this constraint.

The data on attitudes, teaching intentions, and computational thinking are limited to self-report and reflect changes in participants' own assessments of their dispositions and skills; performance-based measures might yield a different pattern. Lesson plan evaluations were similarly limited, as the plans were developed collaboratively in teams, yielding five team-level observations reported through descriptive metrics.

Participants implemented their finalized lesson plans in a setting where peers acted as students rather than in authentic K-12 classrooms. Consequently, how these designs perform during practicum placements or school-based field experiences remains an open question. Future investigations could also examine the decision-making processes guiding preservice teachers during the planning, enactment, and revision phases.

The evaluation of lesson plans was restricted to rubric scores and broad category-level descriptions. More detailed content analyses could further refine existing analytical frameworks for STEM lesson design. The observed overlap between technology and engineering learning objectives also warrants closer inquiry to identify instructional strategies that help preservice teachers conceptually distinguish these disciplines.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors.

*The research was conducted in accordance with ethical guidelines, and approval was granted by the Ethics Committee of Afyon Kocatepe University (Meeting No: 16, Decision No: 2022/24).

Conflict of Interest

*The authors declare that they have no conflicts of interest.

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References

- Adams, A. E., Miller, B. G., Saul, M., & Pegg, J. (2014). Supporting elementary pre-service teachers to teach STEM through place-based teaching and learning experiences. *Electronic Journal of Science Education, 18*(5), 1–22.
- Aho, A. V. (2012). Computation and computational thinking. *The Computer Journal, 55*(7), 832–835.
- Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes, 50*(2), 179–211.
- Al Salami, M. K., Makela, C. J., & de Miranda, M. A. (2017). Assessing changes in teachers' attitudes toward interdisciplinary STEM teaching. *International Journal of Technology and Design Education, 27*(1), 63–88.
- Aldahmash, A. H., Alamri, N. M., & Aljallal, M. A. (2019). Saudi Arabian science and mathematics teachers' attitudes toward integrating STEM in teaching before and after participating in a professional development program. *Cogent Education, 6*(1), Article 1580852.
- Angeli, C., & Giannakos, M. (2020). Computational thinking education: Issues and challenges. *Computers in Human Behavior, 105*, Article 106185.
- Barr, D., Harrison, J., & Conery, L. (2011). Computational thinking: A digital age skill for everyone. *Learning & Leading with Technology, 38*(6), 20–23.
- Blum, L., & Cortina, T. J. (2007). CS4HS: An outreach program for high school CS teachers. *ACM SIGCSE Bulletin, 39*(1), 19–23.
- Bozkurt Altan, E., & Ucuncuoglu, I. (2019). Examining the development of pre-service science teachers' STEM-focused lesson planning skills. *Eurasian Journal of Educational Research, 19*(83), 103–124.
- Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics, 112*(1), 3–11.
- Brennan, K., & Resnick, M. (2012, April). *New frameworks for studying and assessing the development of computational thinking* [Paper presentation]. Annual meeting of the American Educational Research Association, Vancouver, BC, Canada.
- Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P–12 classrooms. *Journal of Engineering Education, 97*(3), 369–387.
- Bulut, S., Özkaya, A., Şahin, G., Tatlısu, S., Çoşkun, G., & Altun, M. (2022). STEM etkinliklerinin lisansüstü öğrencilerinin entegre FeTeMM öğretim yönelimi, farkındalık ve tutumlarına etkisinin incelenmesi [Examination of the effect of stem activities on graduate students' integrative stem teaching intention, awareness and attitudes]. *Eğitim ve Yeni Yaklaşımlar Dergisi, 5*(1), 1–21.
- Burton, M., Maiorca, C., & Tripp, L. O. (2022). The relationship between teacher candidates' affective dispositions and instructional planning actions in STEM. *Education Sciences, 12*(2), Article 82.
- Bybee, R. W. (2010). What is STEM education? *Science, 329*(5995), 996.
- Bybee, R. W. (2019). Using the BSCS 5E instructional model to introduce STEM disciplines. *Science and Children, 56*(6), 8–12.
- Cansiz, N., & Cansiz, M. (2022). Profiling preservice science teachers' early experiences, beliefs about teaching, and teaching practices. *Research in Science & Technological Education, 40*(2), 149–167.
- Capobianco, B. M., & Rupp, M. (2014). STEM teachers' planned and enacted attempts at implementing engineering design-based instruction. *School Science and Mathematics, 114*(6), 258–270.
- Chen, S.-K., Yang, Y.-T. C., Lin, C., & Lin, S. S. J. (2023). Dispositions of 21st-century skills in STEM programs and their changes over time. *International Journal of Science and Mathematics Education, 21*(4), 1363–1380.
- Corlu, M. S. (2014). FeTeMM eğitimi makale çağrı mektubu [Call for manuscripts on STEM education]. *Turkish Journal of Education, 3*(1), 4–10.
- Corlu, M. S., Capraro, R. M., & Capraro, M. M. (2014). Introducing STEM education: Implications for educating our teachers for the age of innovation. *Education and Science, 39*(171), 74–85.
- Creswell, J. W., & Plano Clark, V. L. (2011). *Designing and conducting mixed methods research* (2nd ed.). Sage.

- Çevik, M., & Ata, R. (2019). Turkish validation of STEAM scale and examination of relations between art attitudes, STEM awareness and STEAM attitudes among pre-service teachers. *i.e.: Inquiry in Education*, 11(2), Article 3.
- Çiftçi, A., Topçu, M. S., & Foulk, J. A. (2022). Pre-service early childhood teachers' views on STEM education and their STEM teaching practices. *Research in Science & Technological Education*, 40(2), 207–233.
- Çolakoğlu, M. H., & Günay Gökben, A. (2017). Türkiye’de eğitim fakültelerinde FeTeMM (STEM) çalışmaları [STEM studies in Turkish faculties of education]. *Journal of Research in Informal Environments*, 2(2), 46–69.
- Çorlu, M. S. (2017). STEM: Bütünleşik öğretmenlik çerçevesi [STEM: Integrated teaching framework]. In M. S. Çorlu & E. Çallı (Eds.), *STEM kuram ve uygulamalarıyla fen, teknoloji, mühendislik ve matematik eğitimi* (pp. 1–10). Pusula.
- Deniş Çeliker, H. (2020). The effects of scenario-based STEM project design process with pre-service science teachers: 21st century skills and competencies, integrative STEM teaching intentions and STEM attitudes. *Journal of Educational Issues*, 6(2), 451–477.
- Dökme, İ., & Koyunlu Ünlü, Z. (2024). An effective intervention using STEM instruction for improving preservice science teachers' self-efficacy. *Research in Science & Technological Education*, 42(4), 930–951.
- Eckman, E. W., Williams, M. A., & Silver-Thorn, M. B. (2016). An integrated model for STEM teacher preparation: The value of a teaching cooperative educational experience. *Journal of STEM Teacher Education*, 51(1), 71–82.
- Ergün, A., & Kıyıcı, G. (2019). The effect of design based science education applications of science teacher candidates on their perceptions of engineering education and engineer. *Pegem Journal of Education and Instruction*, 9(4), 1031–1062.
- Estapa, A. T., & Tank, K. M. (2017). Supporting integrated STEM in the elementary classroom: A professional development approach centered on an engineering design challenge. *International Journal of STEM Education*, 4(1), Article 6.
- Falloon, G., Hatzigianni, M., Bower, M., Forbes, A., & Stevenson, M. (2020). Understanding K-12 STEM education: A framework for developing STEM literacy. *Journal of Science Education and Technology*, 29(3), 369–385.
- Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39(2), 175–191.
- Gömlüksiz, M. N. (2003). İngilizce duyuşsal alana ilişkin bir tutum ölçeğinin geçerlik ve güvenilirliği [Validity and reliability of an attitude scale on affective domain in English course]. *Fırat Üniversitesi Sosyal Bilimler Dergisi*, 13(1), 215–226.
- Grover, S., & Pea, R. (2013). Computational thinking in K–12: A review of the state of the field. *Educational Researcher*, 42(1), 38–43.
- Guzey, S. S., Moore, T. J., & Harwell, M. (2016). Building up STEM: An analysis of teacher-developed engineering design-based STEM integration curricular materials. *Journal of Pre-College Engineering Education Research (J-PEER)*, 6(1), Article 2.
- Guzey, S. S., Ring-Whalen, E. A., Harwell, M., & Peralta, Y. (2019). Life STEM: A case study of life science learning through engineering design. *International Journal of Science and Mathematics Education*, 17(1), 23–42.
- Gülbahar, Y., Kert, S. B., & Kalelioğlu, F. (2019). Bilgi işlemsel düşünme becerisine yönelik öz yeterlik algısı ölçeği: Geçerlik ve güvenilirlik çalışması [Self-efficacy perception scale for computational thinking skills: A validity and reliability study]. *Turkish Journal of Computer and Mathematics Education (TURCOMAT)*, 10(1), 1–29.
- Hacıömeroğlu, G. (2018). Sınıf öğretmeni adaylarının fen, teknoloji, mühendislik ve matematik (FeTeMM) öğretimi yönelim düzeylerinin incelenmesi [Examining elementary pre-service teachers' science, technology, engineering, and mathematics (STEM) teaching intention]. *International Online Journal of Educational Sciences*, 10(1), 183–194.
- Hacıömeroğlu, G., & Bulut, A. S. (2016). Entegre FeTeMM öğretimi yönelim ölçeği Türkçe formunun geçerlik ve güvenilirlik çalışması [Integrative STEM teaching intention questionnaire: A validity and reliability study of the Turkish form]. *Eğitimde Kuram ve Uygulama*, 12(3), 654–669.
- Hiğde, E. (2022). The effects of STEM-based alternative energy activities on STEM teaching intention and attitude. *E-International Journal of Educational Research*, 13(2), 126–141.
- Hiğde, E., Aktamış, H., Arabacıoğlu, T., Şen, H. C., Özün Ünal, D., & Yazıcı, E. (2020). Öğretmen ve öğretmen adaylarının STEM alanlarına yönelik tutumlarının ve STEM öğretimi yönelimlerinin farklı değişkenler açısından incelenmesi [Investigation of teachers' and preservice teachers' attitudes towards STEM fields

- and STEM teaching orientations in terms of different variables]. *Uşak Üniversitesi Eğitim Araştırmaları Dergisi*, 6(1), 34–56.
- Holmlund, T. D., Lesseig, K., & Slavit, D. (2018). Making sense of “STEM education” in K-12 contexts. *International Journal of STEM Education*, 5(1), Article 32.
- Hong, H.-Y. (2014). Developing student-centered teaching beliefs through knowledge building among prospective teachers. In S. C. Tan, H. J. So, & J. Yeo (Eds.), *Knowledge creation in education* (pp. 189–204). Springer.
- International Society for Technology in Education & Computer Science Teachers Association. (2011). *Operational definition of computational thinking for K–12 education*. <http://www.iste.org/docs/pdfs/Operational-Definition-of-Computational-Thinking.pdf>
- Johnson, C. C. (2013). Conceptualizing integrated STEM education. *School Science and Mathematics*, 113(8), 367–368.
- Juškevičienė, A., Stupurienė, G., & Jeviskova, T. (2021). Computational thinking development through physical computing activities in STEAM education. *Computer Applications in Education*, 29(1), 175–190.
- Kartal, B., & Taşdemir, A. (2021). Pre-service teachers’ attitudes towards STEM: Differences based on multiple variables and the relationship with academic achievement. *International Journal of Technology in Education (IJTE)*, 4(2), 200–228.
- Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3(1), Article 11.
- Ketelhut, D. J., Mills, K., Hestness, E., Cabrera, L., Plane, J., & McGinnis, J. R. (2020). Teacher change following a professional development experience in integrating computational thinking into elementary science. *Journal of Science Education and Technology*, 29(1), 174–188.
- Kim, C., Kim, D., Yuan, J., Hill, R. B., Doshi, P., & Thai, C. N. (2015). Robotics to promote elementary education pre-service teachers’ STEM engagement, learning, and teaching. *Computers & Education*, 91, 14–31.
- Kim, D., & Bolger, M. (2017). Analysis of Korean elementary pre-service teachers’ changing attitudes about integrated STEAM pedagogy through developing lesson plans. *International Journal of Science and Mathematics Education*, 15(4), 587–605.
- Koçak, B., Aslan, A., & Capellaro, E. (2019). Fen bilimleri, matematik ve sınıf öğretmen adaylarının FeTeMM öğretimine ilişkin yönelimleri [Science, mathematics and primary pre-service teachers’ intention on STEM teaching]. *Fen Bilimleri Öğretimi Dergisi*, 7(2), 168–188. <https://izlik.org/JA73MZ69BX>
- Korkmaz, Ö., Çakır, R., & Özden, M. Y. (2017). A validity and reliability study of the Computational Thinking Scales (CTS). *Computers in Human Behavior*, 72, 558–569.
- Krueger, R. A., & Casey, M. A. (2014). *Focus groups: A practical guide for applied research* (5th ed.). SAGE.
- Kurup, P. M., Li, X., Powell, G., & Brown, M. (2019). Building future primary teachers’ capacity in STEM: Based on a platform of beliefs, understandings and intentions. *International Journal of STEM Education*, 6(1), Article 10.
- Lesseig, K., Nelson, T. H., Slavit, D., & Seidel, R. A. (2016). Supporting middle school teachers’ implementation of STEM design challenges. *School Science and Mathematics*, 116(4), 177–188.
- Li, Y., Schoenfeld, A. H., diSessa, A. A., Graesser, A. C., Benson, L. C., English, L. D., & Duschl, R. A. (2020). On computational thinking and STEM education. *Journal for STEM Education Research*, 3(2), 147–166.
- Lin, K.-Y., & Williams, P. J. (2016). Taiwanese preservice teachers’ science, technology, engineering, and mathematics teaching intention. *International Journal of Science and Mathematics Education*, 14(6), 1021–1036.
- Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. SAGE Publications.
- Luehmann, A. L. (2007). Identity development as a lens to science teacher preparation. *Science Education*, 91(5), 822–839.
- Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). SAGE Publications.
- Moore, T. J., Johnson, C. C., Peters-Burton, E. E., & Guzey, S. S. (2015). The need for a STEM road map. In C. C. Johnson, E. E. Peters-Burton, & T. J. Moore (Eds.), *STEM road map: A framework for integrated STEM education* (pp. 3–12). Routledge.
- Moore, T. J., Stohlmann, M. S., Wang, H. H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In Ş. Purzer, J. Strobel, & M. E. Cardella (Eds.), *Engineering in pre-college settings: Synthesizing research, policy, and practices* (pp. 35–60). Purdue University Press.
- Mumcu, F., Atman Uslu, N. A., & Yıldız, B. (2023). Teacher development in integrated STEM education: Design of lesson plans through the lens of computational thinking. *Education and Information Technologies*, 28(3), 3443–3474.

- National Academy of Engineering & National Research Council. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press.
- National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.
- Patton, M. Q. (2002). *Qualitative research and evaluation methods* (3rd ed.). SAGE Publications.
- Radloff, J., & Guzey, S. (2017). Investigating changes in preservice teachers' conceptions of STEM education following video analysis and reflection. *School Science and Mathematics, 117*(3–4), 158–167.
- Ribeirinha, T., & Correia, M. (2025). Developing pre-service elementary teachers' self-efficacy for integrated STEM. *STEM Education, 5*(5), 882–907.
- Roehrig, G. H., Moore, T. J., Wang, H. H., & Park, M. S. (2012). Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics, 112*(1), 31–44.
- Ryu, M., Mentzer, N., & Knobloch, N. (2019). Preservice teachers' experiences of STEM integration: Challenges and implications for integrated STEM teacher preparation. *International Journal of Technology and Design Education, 29*(3), 493–512.
- Sanders, M. E. (2009). STEM, STEM education, STEMmania. *The Technology Teacher, 68*(4), 20–26.
- Spikic, S., Van Passel, W., Deprez, H., & De Meester, J. (2023). Measuring and activating iSTEM key principles among student teachers in STEM. *Education Sciences, 13*(1), Article 12.
- Srikoom, W., Faikhamta, C., & Hanuscin, D. L. (2018). Dimensions of effective STEM integrated teaching practice. *K-12 STEM Education, 4*(2), 313–330.
- Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research (J-PEER), 2*(1), Article 4.
- Sun, L., Hu, L., Yang, W., Zhou, D., & Wang, X. (2021). STEM learning attitude predicts computational thinking skills among primary school students. *Journal of Computer Assisted Learning, 37*(2), 346–358.
- Supovitz, J. A., & Turner, H. M. (2000). The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching, 37*(9), 963–980.
- Swaid, S. I. (2015). Bringing computational thinking to STEM education. *Procedia Manufacturing, 3*, 3657–3662.
- Şenyiğit, Ç., & Serin, O. (2022). The role of perceived ICT competencies on primary school pre-service teachers' integrated STEM teaching intentions. *Participatory Educational Research, 9*(6), 221–247.
- Takeuchi, M. A., Sengupta, P., Shanahan, M.-C., Adams, J. D., & Hachem, M. (2020). Transdisciplinarity in STEM education: A critical review. *Studies in Science Education, 56*(2), 213–253.
- Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., Boeve-de Pauw, J., Dehaene, W., Deprez, J., De Cock, M., Hellinckx, L., Knipprath, H., Langie, G., Struyven, K., Van de Velde, D., Van Petegem, P., & Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education, 3*(1), Article 2.
- Tseng, K.-H., Chang, C.-C., Lou, S.-J., & Chen, W.-P. (2013). Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal of Technology and Design Education, 23*(1), 87–102.
- Unfried, A., Faber, M., Stanhope, D. S., & Wiebe, E. (2015). The development and validation of a measure of student attitudes toward science, technology, engineering, and math (S-STEM). *Journal of Psychoeducational Assessment, 33*(7), 622–639.
- van de Pol, J., Volman, M., & Beishuizen, J. (2012). Promoting teacher scaffolding in small-group work: A contingency perspective. *Teaching and Teacher Education, 28*(2), 193–205.
- Wang, H.-H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research (J-PEER), 1*(2), Article 2.
- Wieselmann, J. R., Sager, M. T., & Price, B. C. (2022). STEM project-based instruction: An analysis of teacher-developed integrated STEM PBI curriculum units. *Education Sciences, 12*(9), Article 626.
- Wing, J. M. (2006). Computational thinking. *Communications of the ACM, 49*(3), 33–35.
- Wu, B., Hu, Y., & Wang, M. (2019). Scaffolding design thinking in online STEM preservice teacher training. *British Journal of Educational Technology, 50*(5), 2271–2287.
- Wu, B., Peng, X., & Hu, Y. (2021). How to foster pre-service teachers' STEM learning design expertise through virtual internship: A design-based research. *Educational Technology Research and Development, 69*(4), 3307–3329.
- Yadav, A., Mayfield, C., Zhou, N., Hambrusch, S., & Korb, J. T. (2014). Computational thinking in elementary and secondary teacher education. *ACM Transactions on Computing Education, 14*(1), Article 5.
- Yıldırım, A., & Şimşek, H. (2016). *Sosyal bilimlerde nitel araştırma yöntemleri* [Qualitative research methods in the social sciences] (10th ed.). Seçkin Yayıncılık.
- Yip, W. Y. V. (2020). Developing undergraduate student teachers' competence in integrative STEM teaching. *Frontiers in Education, 5*, Article 44.

- Zeng, Y., Yang, W., & Bautista, A. (2023). Teaching programming and computational thinking in early childhood education: A case study of content knowledge and pedagogical knowledge. *Frontiers in Psychology, 14*, Article 1252718.
- Zhang, Y., & Zhu, J. (2023). STEM pre-service teacher education: A review of research trends in the past ten years. *Eurasia Journal of Mathematics, Science and Technology Education, 19*(7), Article em2292.

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