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Developing the Research Skills of Future Primary School Teachers through STEM: An Empirical Evaluation

Abstract

Introduction. Pre-service primary school teachers are expected to work with evidence, classroom problems, and small-scale inquiries, rather than relying solely on ready-made pedagogical knowledge. The present study examines how a voluntary extracurricular program grounded in science, technology, engineering, and mathematics (STEM) supports the development of research skills among prospective primary school teachers. *Materials and Methods.* The study used a quasi-experimental pre-test and post-test design. The program took place outside regular classroom hours and included inquiry-oriented tasks, project work, collaborative problem-solving, evidence analysis, presentation of findings, and guided reflection. The assessment of students' research skills used an adapted questionnaire focused on critical thinking, the application of research methods, and reflection. *Results.* The findings demonstrated positive changes in students' general research skills and in the main components of research activity. *Scientific novelty.* The study shows that science, technology, engineering, and mathematics can serve not only as interdisciplinary learning tools but also as a pedagogical environment for building a research culture in teacher education. *Practical significance.* The proposed program could help teacher education institutions improve students' preparedness for inquiry-based and project-oriented professional practice.

Keywords: STEM technology, pre-service primary school teachers, research skills, quasi-experiment, pre-test and post-test, reflection.

Introduction. The contemporary era is transitioning from the “information age” to the “age of synthesis,” a shift that requires integrating knowledge from diverse scientific and practical domains (Nadelson & Seifert, 2017). This process has increased demand for individuals in the labor market who can quickly assimilate scientific and technological advancements, demonstrate advanced cognitive abilities, and address complex challenges (Hebebcı & Usta, 2022). Consequently, the conventional educational framework is undergoing a transition towards dynamic learning methodologies designed to cultivate 21st-century competencies within the context of the Sustainable Development Goals (Rehman

et al., 2025). These changes necessitate adjustments and a fundamental rethinking not only of the curriculum context but also of teachers' professional roles. In this context, the STEM (science, technology, engineering, and mathematics) education model has gained widespread recognition as an effective approach to fostering critical thinking, scientific creativity, and problem-solving skills (Hebebcı & Usta, 2022; Nguyen et al., 2020).

The STEM approach is not confined to knowledge integration; it focuses on organizing inquiry-based learning activities to enhance students' cognitive engagement. Nevertheless, STEM education's potential largely focuses on students, with limited attention to the research

training of the teachers who implement it. Recent studies demonstrate that preparing future primary and elementary school teachers for integrated science, technology, engineering, and mathematics (STEM) education remains an important yet underdeveloped area of teacher education. Many pre-service elementary teachers lack confidence in teaching integrated STEM (Menon et al., 2023; Wieselmann et al., 2025).

These individuals tend to rely on short-term course experiences, lesson-planning tasks, and opportunities to observe or practice integrated instruction. Research on primary pre-service teachers further indicates that practical experiences, such as makerspace activities, inquiry-based tasks, and engineering design practices, can strengthen their confidence, attitudes, and readiness for interdisciplinary teaching (Halliburton et al., 2024; Lupión-Cobos et al., 2026). These findings emphasize the need to examine not only students' learning outcomes but also the research-oriented preparation of future teachers expected to design, implement, and evaluate integrated learning activities. Teachers' professional development programs must foster a growth mindset, encourage critical reflection on practice, and support evidence-based pedagogical decision-making (Milner-Bolotin, 2018; Vossen et al., 2020). These requirements underscore the significance of intentionally cultivating a research culture during the initial stage of teacher education. Nevertheless, existing research suggests that prospective teachers lack awareness of STEM education programs. For instance, as Anisimova et al. (2020) demonstrate, only 18% of students exhibit adequate comprehension of the STEM context, while only 10% report feeling prepared to organize project-based research activities (Anisimova et al., 2020).

Despite the evident enthusiasm among prospective primary school teachers for STEM subjects, their grasp of multidisciplinary and practical research skills remains limited. This suggests a gap in STEM education development, particularly in teacher training programs, where the STEM approach remains predominantly theoretical. Prospective educators need to

develop a research culture systematically. First, STEM is intended as a formal integration of subjects; however, teachers do not fully use their research skills and multidisciplinary potential (El Nagdi et al., 2018; Nadelson & Seifert, 2017). Second, teacher education programs often teach research and design activities in isolation. This hinders future teachers' ability to apply scientific knowledge to solve authentic pedagogical problems (Vossen et al., 2020). Third, many teachers struggle to integrate engineering and technological elements into their lessons (extrinsic challenges), which is linked to insufficient interdisciplinary knowledge (Dong et al., 2020). Empirical studies examining the impact of STEM technologies on the research competence of future primary school teachers remain limited. In this regard, investigating the effectiveness of STEM-based courses in developing the research skills of future primary school teachers is a relevant problem.

Contemporary scientific literature conceptualizes STEM education (science, technology, engineering, and mathematics) not only as the integration of knowledge but also as a pedagogical approach that employs inquiry- and design-based activities to solve real-world problems. Research undertaken within the domain of early education has indicated that STEM-based teaching sequences, which are oriented towards the development of students' inquiry skills – encompassing the formulation of questions, the generation of hypotheses, observation, practice, the collection of data, and evidence-based reasoning (Rúa Martínez et al., 2024) – are conducive to this process. Systematic reviews of STEAM practices at the primary school level support this direction. STEAM/STEM interventions have been shown to enhance students' learning engagement, knowledge, and skills (Yim et al., 2025). However, the effectiveness of these interventions is contingent on developing teachers' methodological preparedness and providing sustained professional support. Consequently, the efficacy of STEM education depends not solely on the "individual method" but largely on educators' systemic professional competence and the affordances of their

learning environments. Research skills at the primary school level are a complex competence that develops progressively, from initial curiosity to purposeful questioning, information gathering, data collection, analysis, and drawing conclusions. Pedagogues have observed that research skills do not develop spontaneously; rather, lesson effectiveness improves when teachers implement well-organized tasks, provide guiding questions, and offer systematic feedback (Aktepe & Ulu, 2023).

This finding emphasizes the critical role of pedagogical design and the teacher's facilitative function in fostering a research-oriented culture. Recent literature has increasingly emphasized that science, technology, engineering, and mathematics education in teacher preparation should be organized around active inquiry, design-based tasks, collaboration, and reflection. Research on design-based science, technology, engineering, and mathematics (STEM) activities indicates that such tasks can cultivate preservice teachers' design thinking, problem formulation, solution testing, and evaluation skills (Yüksel, 2025).

In a similar vein, studies examining integrated science, technology, engineering, and mathematics education in primary and elementary settings have underscored the significance of authentic problems, interdisciplinary connections, teacher facilitation, and structured learning environments (Cheek et al., 2025; Rúa Martínez et al., 2024; Yim et al., 2025). From this standpoint, cultivating research aptitudes among prospective primary school educators is integral to comprehensive professional preparation, since inquiry, evidence analysis, methodological selection, and reflection are pivotal to both research endeavors and integrated science, technology, engineering, and mathematics pedagogy. In teacher training, several studies have shown that introducing STEM inquiry-based learning in short-term programs is ineffective.

The creation of a robust foundation of interdisciplinary learning designs, research project cycles, and evaluation tools at the primary school level requires long-term preparation (Yim et al., 2025). Research undertaken within the Kazakhstani context

demonstrates that the implementation of STEM education is influenced by institutional and social factors, underscoring the substantial interconnections between teacher agency and classroom practice. This underscores the need to consider local contextual conditions when evaluating the effectiveness of STEM-based interventions (Durrani & Kataeva, 2025). The extant literature consistently emphasizes the potential of STEM/STEAM approaches to foster inquiry skills in primary education (Rúa Martínez et al., 2024; Yim et al., 2025). Similarly, Tolkynbayeva et al. (2026) found that systematically integrating STEM-based inquiry tasks supports the development of research skills, including hypothesis formulation, data analysis, problem-solving, and project-based investigation. However, empirical studies in post-Soviet contexts such as Kazakhstan examining the effectiveness of semester-long STEM-based interventions to develop inquiry skills among future primary school teachers, using a pre-test/post-test design, remain limited (Durrani & Kataeva, 2025). In response to this gap, the present study seeks to empirically assess the impact of a STEM technology-based course on the development of inquiry skills among future primary school teachers, including its core components: critical thinking, application of research methods, and reflection (Aktepe & Ulu, 2023; Yim et al., 2025).

This study aims to determine the impact of STEM-technology-based courses on the research skills of future primary school teachers. To achieve this objective, the study seeks to develop technological and pedagogical knowledge by employing the method "Model - Reflection - Research-Practice" (Milner-Bolotin, 2018), enhance their self-efficacy in research activities by fostering a personal pedagogical philosophy aligned with STEM, and evaluate the effectiveness of integrating research and design cycles within Professional Learning Communities (Vossen et al., 2020).

In accordance with the purpose of this study, the following research questions were formulated:

1. Does a voluntary extracurricular program based on science, technology, engineering, and

mathematics have a statistically significant effect on the overall level of research skills of future primary school teachers?

2. Which components of research skills show the most evident changes after the intervention: critical thinking, application of research methods, or reflection?

3. How are students' research skills reflected in their learning products and reflective notes during the program?

Materials and Methods. Research Design. The study used a quasi-experimental one-group pretest/posttest design. This design was selected to examine changes in future primary school teachers' research skills before and after participation in a voluntary extracurricular program grounded in science, technology, engineering, and mathematics. The pre-test was administered before the intervention, and the post-test after the program's completion. Comparing the two measurements enabled identification of changes in students' research skills following the intervention.

Research Model. The intervention was organized as a voluntary extracurricular program to develop students' research skills through inquiry-oriented and project-based activities. The program was conducted outside standard classroom hours and was not mandatory. The program focused on the key phases of research, including identifying research problems, formulating research questions, selecting appropriate methods, collecting data, analyzing evidence, developing arguments, presenting results, and reflecting. Students completed individual and group assignments related to pedagogical scenarios and small-scale research issues. The collaborative learning approach entailed group discussions, role distribution, joint decision-making, and the presentation of findings. The program helped students engage with research not only as theoretical knowledge but also as a series of practical actions linked to future teaching practice.

Participants. The participants were undergraduate students majoring in Primary Education Pedagogy and Methodology. The study comprised 26 students. Participation in the extracurricular program was voluntary. Prior

to the commencement of the intervention, the study objective was explained to the students. The subjects were informed that the collected data would be used solely for research purposes and kept confidential.

Data Collection Tools. The primary data collection instrument was a 25-item questionnaire designed to evaluate students' research aptitudes. The questionnaire was adapted from the research skills instrument presented in "Development and Validation of Research Skills Instruments for Pre-service Biology Teachers". The items were reformulated to align with the academic and professional contexts of future primary school teachers while preserving the original instrument's core logic. The questionnaire encompassed three components of research skills: critical thinking, the application of research methods, and reflective skills. Responses were evaluated using a five-point Likert scale.

Data Collection Process. Data was collected in two stages during the voluntary extracurricular intervention. In the first stage, students completed the questionnaire before the program began. The intervention was then implemented outside regular classroom hours through inquiry-oriented tasks, project work, collaborative activities, evidence analysis, presentation of findings, and guided reflection. In the second stage, the same questionnaire was administered after the program. During the intervention, students produced learning materials such as project plans, short reports, task outcomes, presentations, and reflective notes. These materials helped clarify how students engaged with research-oriented tasks and applied research skills in practical educational situations.

Ethical Consideration. The study followed the ethical principles of the Declaration of Helsinki and relevant national regulations on research involving human participants. The research was limited to a non-interventional educational program and an anonymous questionnaire survey of adult university students; it involved no medical, clinical, or biomedical procedures, no deception, and no collection of sensitive personal data. Under the institutional regulations

in force, studies of this type do not require review by a formal ethics committee.

Participation in both the extracurricular program and the survey was entirely voluntary. Before the intervention began, students were informed of the study's aims, the procedures involved, and that the data would be used for research purposes only, and they gave informed consent to participate. They were advised that they could decline to take part or withdraw at any stage without giving reasons, and that neither participation nor withdrawal would affect their academic assessment or their relationship with the teaching staff. No incentives were offered.

Questionnaire responses were coded numerically without names or other identifiers; the codes linking pre-test and post-test responses were held separately and destroyed once the data had been matched. Students' learning products and reflective notes were analyzed in anonymized form, and all data are reported exclusively in aggregated form, without details that would permit the identification of individual participants.

Data Analysis. Quantitative data was processed using statistical software. First, we calculated descriptive statistics, including mean

and standard deviation, for the overall research skills score and each component. The normality of the data was then checked. To compare pre-test and post-test results, a paired-samples t-test was applied. The magnitude of the intervention effect was determined using Cohen's *d*. Students' learning products and reflective notes were analyzed descriptively to support the interpretation of the quantitative findings.

Results. The study compared the overall level of research skills among future primary school teachers using pre- and post-test results. The findings indicated that students' overall research skills improved substantially after the training intervention. Before the intervention, the average general research skills score was 41.12 (SD = 4.56). However, following the intervention, this score increased to 53.38 (SD = 5.21) (Table 1). The difference between the means indicates that students acquired more research skills through the learning process. The approximate standard deviation values indicate that the indicators within the group are relatively uniform. The findings of this study provide compelling evidence that the training intervention positively impacted the development of research skills among future teachers.

Table 1

Descriptive statistics for pre-test and post-test scores (n=26)

		Descriptive Statistics			
	N	Minimum	Maximum	Mean	Std. Deviation
Pre-test	26	33	52	41.12	4.555
Post-test	26	45	67	53.38	5.208

We examined data normality using the Kolmogorov–Smirnov test. For most variables, no statistically significant deviations were detected ($p > 0.05$), indicating that the data could be assumed to be approximately normally distributed. Accordingly, a paired-samples t-test was applied as a parametric method to compare pre-test and post-test results. The paired t-test was used to determine the statistical significance of the differences between pre-test and post-test scores. The analysis showed a statistically significant difference between pre-test and post-test results for the overall level of research skills.

The mean difference between pre-test and post-test scores was -12.27 points, indicating that post-test scores were higher than pre-test scores. The 95% confidence interval for the mean difference ranged from -13.37 to -11.17 and did not include zero, demonstrating the stability and reliability of the obtained results. The paired t-test revealed a highly significant difference between the two measurements ($t(25) = -22.99$, $p < .001$) (Table 2). These findings indicate that the instructional intervention had a clear and systematic effect on improving the overall research skills of future primary school teachers.

Table 2

Paired t-criterion results for comparing pre-test and post-test results by General research skill level (n=26)

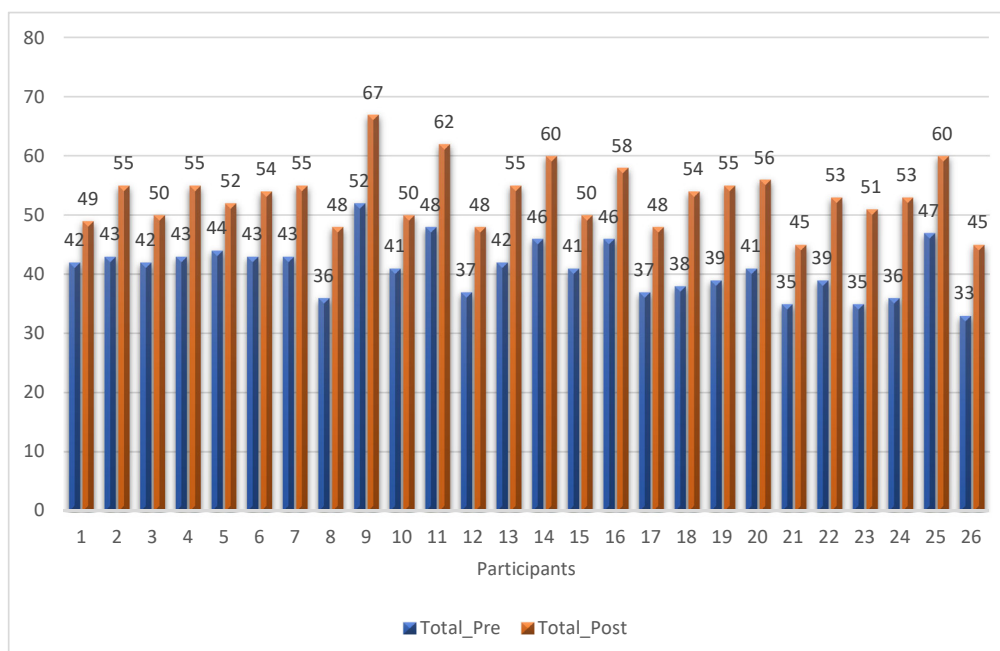
Paired Samples Test									
Paired Differences						t	df	Significance	
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				One- Sided p	Two- Sided p
				Lower	Upper				
Total_Pre - Total_Post	-12.269	2.721	.534	-13.368	-11.170	-22.991	25	<.001	<.001

Figure 1 presents the pre-test and post-test results for the overall research skills of future primary school teachers, displayed individually for each participant. The graph clearly shows that post-test scores are higher than pre-test scores for nearly all participants. While pre-test scores were mainly clustered between 33 and 52 points, post-test scores increased to a range of 45–67 points. These results show that, following the instructional intervention,

research skills improved not only in terms of mean values but also consistently at the level of individual participants. Although the magnitude of improvement was more pronounced for some participants and relatively smaller for others, the overall trend across all participants is clearly positive. This pattern suggests the intervention's effect was stable and consistent despite individual differences.

Figure 1

Comparison of Pre-test and Post-test results by individual participants



The analysis conducted across the components of research skills also revealed positive dynamics in all dimensions. For the critical thinking component, the mean score at

the pre-test stage was 14.08 (SD = 2.40), which increased to 18.04 (SD = 3.22) at the post-test stage. This indicates improved students' ability to analyze information, evaluate evidence, and

make well-reasoned decisions. A clear increase was also observed in the component related to applying research methods. The mean pre-test score was 16.23 (SD = 2.94), while the post-test score rose to 21.12 (SD = 3.46). These results suggest that future teachers developed a stronger understanding of research methods and a greater capacity to apply them in their learning. The reflection component also showed positive changes. The mean score increased from 10.81 (SD = 2.70) at the pre-test stage to 14.23 (SD = 3.01) at the post-test stage, indicating greater ability to analyze one's own learning activities, evaluate outcomes, and assume responsibility for professional development. Overall, the

component-level results show stable, systematic gains across all core dimensions of research skills. The analysis confirmed that differences were statistically significant not only for the overall research skills score but also for each component ($p < .001$). In particular, post-test results for critical thinking, application of research methods, and reflection were substantially higher than pre-test scores, confirming that these changes were not random (Table 3). Taken together, the findings provide evidence that the implemented instructional program had a meaningful effect, not only statistically but also pedagogically, in fostering the research skills of future primary school teachers.

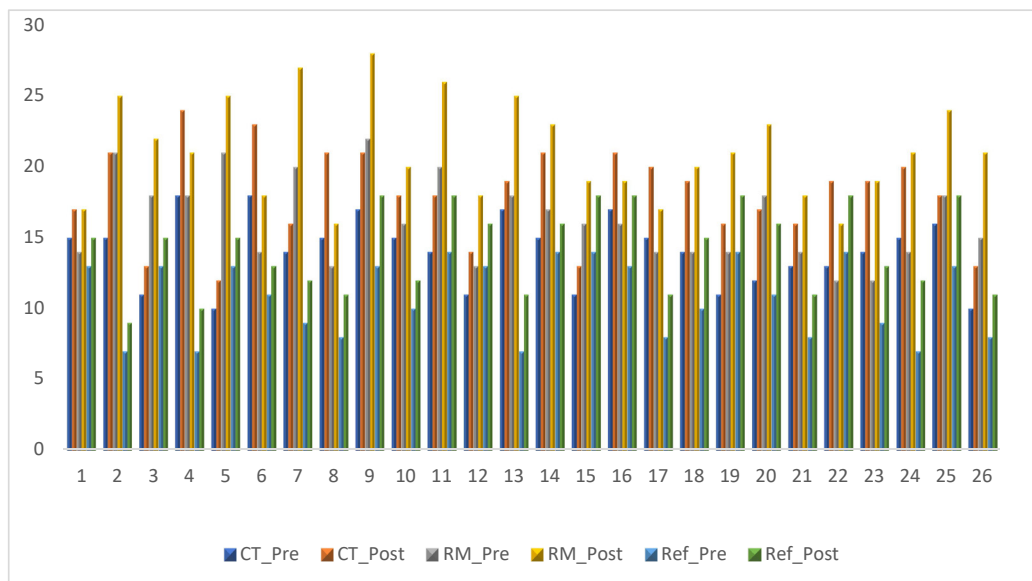
Table 3

Results of Paired Samples T-Tests Comparing Pre-test and Post-test Scores across Research (Skill Components)

Paired Samples Test									
Paired Differences						t	df	Significance	
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				One- Sided p	Two- Sided p
				Lower	Upper				
Critical thinking	-3.962	1.536	.301	-4.582	-3.341	-13.153	25	<.001	<.001
Application of research method	-4.885	1.505	.295	-5.493	-4.277	-16.545	25	<.001	<.001
Reflection	-3.423	1.137	.223	-3.883	-2.964	-15.345	25	<.001	<.001

Figure 2 shows changes in pre-test and post-test results at the level of individual participants in the main components of the research skills of future primary school teachers: critical thinking, application of research methods, and reflection. The graph shows that post-test indicators for all components are higher than the pre-test results. Growth is especially pronounced in the use of research methods component, indicating an increase in students'

ability to master research approaches and apply them in the educational process. In the critical thinking and reflection components, results also show a steady upward trend during the post-test period. Although indicators fluctuate among individual participants, the overall trend remains positive across all components. These graphs visually confirm the effectiveness of the training intervention in all key components of research skills.

Figure 2*Dynamics of pre-test and post-test results on research skills components*

Note. CT = critical thinking; RM = application of research methods; Ref = reflection

Discussion. This study aimed to evaluate the impact of a semester-long STEM technology-based course on the research skills of future primary school teachers. The results showed a clear increase in overall research skills after the intervention: pre-test period $M = 41.12$ ($SD = 4.56$), post-test period $M = 53.38$ ($SD = 5.21$). A paired-samples t-test confirmed that this difference was statistically significant ($t(25) = -22.99$, $p < .001$, 95% CI $[-13.37; -11.17]$). Component-level analysis revealed a consistent pattern of positive change across all dimensions. Statistically significant improvements were observed in critical thinking ($t(25) = -13.15$, $p < .001$), application of research methods ($t(25) = -16.55$, $p < .001$) and reflection ($t(25) = -15.35$, $p < .001$). Thus, the findings demonstrate that upon completion of the course, the cognitive (critical thinking), instrumental (use of research methods), and metacognitive (reflection) components of students' research skills developed simultaneously. Compared with previous studies, much of the existing literature characterizes the effectiveness of STEM interventions primarily through student-level learning outcomes, such as problem-solving ability, critical thinking, scientific creativity, and increased interest in learning (Hebebe & Usta,

2022; Ortiz-Revilla et al., 2020). In this respect, the present findings extend existing evidence by demonstrating that the potential of the STEM approach is not limited to learners alone but also applies to the professional preparation of future teachers, particularly in relation to their research skills. This aligns with the logic of research-oriented learning discussed by Ceylan (2014), as research activity itself unfolds through stages of problem identification, hypothesis formulation, evidence collection, and conclusion drawing (Ceylan, 2014).

At the same time, several studies have reported weak or non-significant effects of STEM interventions, often attributing these outcomes to the short duration of the intervention (Değerli & Yapıcı, 2022). In the present study, the systematic organization of the intervention over an entire semester may be a key factor underlying the observed gains. The extended timeframe, combined with repeated learning cycles, likely created favorable conditions for consolidating research skills. To better understand the mechanisms behind these results, it is important to consider the course's instructional logic. STEM technologies shift learning from passive information reception to active inquiry and knowledge construction,

encouraging learners to formulate research questions, work with data, and justify their solutions (Dong et al., 2020). This effect is particularly pronounced in design-based learning contexts, where learners identify a problem, develop or test a prototype or solution, and refine outcomes through iterative cycles (Nguyen et al., 2020).

Moreover, the interconnection between research and design plays a critical role: research informs design decisions, while design activities generate new research questions. This integration strengthens future teachers' ability to connect scientific knowledge with pedagogical tasks (Vossen et al., 2020). The parallel improvement observed across all research skill components supports this interpretation. Students demonstrated not only improved data collection abilities, but also greater capacity for critical evaluation and evidence-based reasoning (Daryanes et al., 2025). The positive dynamics observed in the reflection component further suggest that the metacognitive core of research culture - self-evaluation, error recognition, and planning subsequent steps - can be effectively fostered through structured instructional tasks (Milner-Bolotin, 2018).

Additional factors may also help explain the findings in the context of future primary school teachers. Previous research indicates that while pre-service teachers often express strong interest in STEM, they struggle to establish interdisciplinary connections and translate research-design cycles into concrete lesson plans. Students in teacher education programs also tend to feel more confident in mathematical components, while reporting lower preparedness when integrating natural sciences and technology elements (Kurup et al., 2019). In such contexts, structured approaches such as "Modeling-Reflection-Research-Practice" may support the gradual mastery of complex activities and enhance students' sense of self-efficacy (Milner-Bolotin, 2018). Furthermore, social factors, including gender stereotypes, may indirectly influence motivation to engage with STEM fields. Therefore, interpreting the results through the lens of professional beliefs and cultural context is both relevant and necessary

(Durrani & Kataeva, 2025). From a practical perspective, the results highlight the importance of planning STEM-based courses in teacher education institutions in a systematic, long-term format to support the development of research skills. Such courses can be effective when they move beyond theoretical introductions and consistently incorporate problem formulation based on authentic pedagogical situations, small-scale research tasks, project work, presentation and defense of results, and reflective analysis. However, because teachers frequently cite time constraints for lesson planning and material preparation as significant barriers, future implementations should address methodological support and resource provision alongside curriculum design (Margot & Kettler, 2019).

The limitations of this study must be shown at the analysis interpretation stage. First, the use of a single-group pre-test/post-test design without a control group increases threats to internal validity, as the observed improvements may also be influenced by testing effects or time-related factors. Second, the small sample size ($N = 26$) and the focus on a single institutional context limit the generalizability of the findings. Third, as the primary measurement instrument relied on self-report data, the possibility of socially desirable responses cannot be excluded. Future studies would benefit from triangulation through rubric-based assessment of student products (e.g., project plans, reports, presentations), classroom observations, and expert evaluations. Fourth, the absence of follow-up measurements does not allow conclusions about the long-term sustainability of the observed effects. Given these limitations, future research using quasi-experimental designs with control groups, multi-site samples, and longitudinal follow-up measures would strengthen conclusions about the effectiveness of STEM-based interventions. Overall, the study shows that a semester-long STEM technology-based course leads to statistically significant positive changes in the research skills of future primary school teachers across all major components. These findings underscore the potential of the STEM approach as a purposeful tool for cultivating research

culture within teacher education, while also highlighting the need for further research using more robust designs to reinforce the evidence base.

Conclusion. The present study demonstrated that a voluntary extracurricular program grounded in science, technology, engineering, and mathematics can support the development of research skills among future primary school teachers. The program facilitated student engagement with the fundamental stages of inquiry, including identifying educational problems, formulating research questions, selecting appropriate methods, analyzing evidence, presenting findings, and reflecting on learning decisions. The findings suggest that students' research capabilities have improved not only in overall proficiency but also across the primary components of research activity: critical thinking, the application of research methods, and reflection.

The primary contribution of this study is that it presents science, technology, engineering, and mathematics as more than an interdisciplinary

teaching approach. In teacher education, it can serve as a practical pedagogical environment that cultivates an inquiry culture, evidence-based thinking, and reflective professional action. This is particularly significant for prospective primary school teachers, as their professional preparation should encompass not only subject and methodological expertise, but also the capacity to analyze classroom issues through a research-oriented lens.

The study also posits that research skills develop more effectively when students engage in practical, collaborative, and reflective tasks rather than when research is taught solely as a theoretical requirement. The findings may be of use to teacher education programs seeking to strengthen students' readiness for inquiry-based and project-oriented professional practice. Subsequent studies may extend this research by utilizing larger samples, incorporating control groups, and implementing delayed follow-up measurements to assess the longevity of the observed alterations.

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