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The Role of STEM Education in Teacher Training: A Study on Critical Thinking and Technological Attitudes

STEM Eğitiminin Öğretmen Yetiştirmedeki Rolü: Eleştirel Düşünme ve Teknolojik Tutumlar Üzerine Bir İnceleme

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ABSTRACT

The purpose of this study is to examine the effect of STEM education on the cognitive and affective development of teacher candidates. The variables examined in the study include teacher candidates' critical thinking skills, attitudes toward robotic technologies, interest in astronomy, and general attitudes toward STEM. The research was conducted using a quantitative method and adopted a quasi-experimental design. The effects of STEM education were evaluated by analyzing the data from the pre-test, post-test, and retention test conducted four weeks later with the participants. In addition, written feedback was collected using open-ended questions to gather qualitative data on teacher candidates' learning experiences. According to the research results, STEM education was found to have statistically significant improvements, particularly in teacher candidates' critical thinking skills and attitudes toward robotic technologies. This indicates that the applied and problem-based structure of STEM positively affects thinking processes and the level of technological interest. However, no statistically significant difference was found in variables such as interest in astronomy and general attitude toward STEM. The findings of the retention test revealed that the gains achieved were sustainable. Qualitative findings indicating that participants were able to relate their learning experiences to daily life show that learning became meaningful. In line with the research findings, STE should be included in teacher training programs.

Keywords: STEM education, pre-service teachers, critical thinking, robotics, astronomy.

ÖZ

Bu araştırmanın amacı, STEM eğitiminin öğretmen adaylarının bilişsel ve duyuşsal gelişimleri üzerindekietkisini incelemektir. Araştırma kapsamında ele alınan değişkenler arasında öğretmen adaylarınıneleştirel düşünme becerisi, robotik teknolojilere yönelik tutumu, astronomiye ilgisi ve genel STEMtutumu yer almaktadır. Araştırma, nicel bir yöntemle yürütülmüş ve yarı deneysel desenbenimsenmiştir. Katılımcılara uygulanan ön test, son test ve dört hafta sonra gerçekleştirilen kalıcılıktesti verileri analiz edilerek STEM eğitiminin etkisi değerlendirilmiştir. Ayrıca öğretmen adaylarındanöğrenme deneyimlerine ilişkin nitel veri toplamak amacıyla açık uçlu sorularla yazılı geri bildirimleralınmıştır. Araştırma sonuçlarına göre, STEM eğitimi öğretmen adaylarının özellikle eleştirel düşünmebecerilerinde ve robotik teknolojilere yönelik tutumlarında istatistiksel olarak anlamlı gelişim sağlandığıtespit edilmiştir. Bu durum, STEM'in uygulamalı ve problem temelli yapısının düşünme süreçlerini veteknolojik ilgi düzeyini olumlu etkilediğini göstermektedir. Ancak astronomiye ilgi ve genel STEMtutumu gibi değişkenlerde istatistiksel olarak anlamlı bir fark oluşmamıştır. Kalıcılık testi bulguları, eldeedilen kazanımların sürdürülebildiğini ortaya koymuştur. Katılımcıların öğrenme deneyimlerini günlükyaşamla ilişkilendirebildiklerine dair nitel bulgular ise öğrenmenin anlamlı hâle geldiğini göstermektedir.Araştırma bulguları doğrultusunda, öğretmen yetiştirme programlarında STEM eğitiminin sistematikbiçimde yapılandırılması gerektiği, içeriklerin branşlara özgü olarak farklılaştırılması ve öğretmenadaylarının uygulamalı öğrenme fırsatlarıyla desteklenmesinin önemi vurgulanmaktadır..

Anahtar kelimeler: STEM eğitimi, öğretmen adayları, eleştirel düşünme, robotik, astronomi.

Introduction

Global dynamics such as digital transformation, artificial intelligence, sustainable development, and the growing demand for interdisciplinary innovation have reshaped the expectations placed upon education systems in the 21st century. These changes require not only rethinking how students learn but also redefining what teachers need to know and be able to do. Around the world, education reforms increasingly emphasize inquiry-based, technology-integrated, and problem-oriented approaches that prepare learners for complex global challenges (OECD, 2023; Bybee, 2010; Zollman, 2012). Within this context, the STEM (Science, Technology, Engineering, and Mathematics) approach provides a theoretical foundation for cultivating 21st-century skills—such as critical thinking, creativity, and collaboration—through the integration of disciplinary knowledge and real-world problem solving (English, 2016). Implementing STEM-oriented education, however, necessitates systemic restructuring in several domains, including curriculum design, teacher training, assessment systems, and learning environments (Honey, Pearson, & Schweingruber, 2014).

In Turkey, this global educational transformation finds its local reflection in the Turkish Century Education Model (TCEM), which represents a new framework grounded in values-based, skill-oriented, and holistic principles of education. The model emphasizes key competencies such as interdisciplinary thinking, problem solving, digital literacy, and entrepreneurship, which directly align with the core objectives of STEM education (MoNE, 2024).

The STEM approach has become a leading educational paradigm worldwide in fostering 21st-century skills. In countries such as the United States, South Korea, Finland, and Singapore, STEM education is implemented as an integrated instructional model aimed at developing students' problem-solving, critical thinking, creativity, and innovation skills (Bybee, 2013; English, 2016). In the United States, STEM education is supported at the national level as part of policies to develop human resources in science and engineering, and it is structured within the framework of the Next Generation Science Standards (NGSS), which integrate science, technology, engineering, and mathematics disciplines (NRC, 2013). Similarly, in Finland, STEM activities are implemented from early childhood education through interdisciplinary, project-based learning practices that promote inquiry- and research-based learning experiences (Sheth & Pathak, 2023). In Singapore, STEM education is at the core of the national curriculum and is reinforced through laboratories and design studios that aim to foster innovative thinking and entrepreneurial skills among students (Tan & Ng, 2019).

This global trend demonstrates that STEM is regarded not merely as an educational approach but as a key driver of economic and technological development. In Türkiye, the STEM approach was integrated into the Science Curriculum updated in 2018 under the title "Science, Engineering and Entrepreneurship Practices" (MoNE, 2018). However, the effective implementation of this approach in the classroom requires teachers to master not only content knowledge but also the integration of technology, pedagogical strategies, and content knowledge. In this context, STEM teaching should be handled within the framework of TPACK model (Technological Pedagogical Content Knowledge); pre-service teachers should be supported both to use digital technologies effectively and to transform this knowledge pedagogically (Mishra & Koehler, 2006).

Recent studies show that STEM-based practices, especially in pre-service teacher education, have positive effects on teachers' professional competence, motivation, and innovative tendencies. Research in various contexts supports these findings. For instance, Kelley and Knowles (2016) highlighted that integrated STEM education enhances pre-service teachers' pedagogical design capacity and fosters interdisciplinary teaching perspectives. Similarly, Han, Capraro, and Capraro (2015) found that STEM project-based learning improves pre-service teachers' problem-solving and creativity skills through authentic, inquiry-oriented activities. In Finland, Jutty et al. (2020) emphasized that STEM-integrated training contributes to developing teachers' technological pedagogical knowledge and confidence in classroom applications. Moreover, English (2017) and Thibaut et al. (2018) demonstrated that STEM education promotes higher-order thinking, collaboration, and innovation-oriented attitudes among pre-service teachers across different countries.

In Türkiye, similar patterns have been reported. Şahin and Yıldız (2022) revealed that pre-service teachers who received STEM education showed significant improvement in problem-solving, creativity, and critical thinking skills. Altun (2024) found that STEM-oriented training enhanced teachers' interest and positive attitudes toward robotics applications. More recent studies have also underlined significant differences in technology integration competencies and interdisciplinary thinking capacities among pre-service teachers with STEM experience (Verdi & Balım, 2023; Karataş Aydın & Sipahi, 2023).

STEM education affects not only skill development but also the professional identity development of pre-service teachers. Unlike traditional teacher roles, the STEM approach positions the pre-service teacher not as a "knowledge transmitter" but as an individual who directs learning processes, designs and produces with technology. In this context, STEM practices increase pre-service teachers' perception of professional self-efficacy, strengthen their classroom leadership skills, and improve their potential to create learning communities (Gülgün et al., 2017; Yıldırım & Türk, 2018).

Another reason underlining the importance of STEM in the Turkish context is international achievement indicators. Recent PISA and TIMSS results show that Turkish students perform lower than their peers in higher order thinking, application and interpretation skills (OECD, 2023). Transferring STEM practices to students through teachers at an early age offers an effective strategy to close these gaps. The most important element that will strengthen the educational pillar of Türkiye's initiatives such as the National Technology Move, TEKNOFEST, and TÜBİTAK 4004-4005 projects is teachers who are predisposed to STEM and pedagogically equipped.

In this context, teacher education programs in many countries have made STEM components compulsory modules. For example, in the United States, "Engineering Leadership Teaching" models are developed for STEM teacher education, and interdisciplinary modular teacher education programs are implemented in Finland. OECD (2022) and UNESCO (2023) reports emphasize that future educators should be equipped with technology integration, creativity, engineering design and problem solving skills. In this context, enriching teacher training programs in Türkiye with STEM practices is a critical need at both global and national levels.

Furthermore, pre-service teachers' backgrounds and specializations may influence how they perceive and implement STEM practices. Research indicates that differences in subject-area orientation (e.g., early childhood, elementary, or science education) affect teachers' pedagogical perspectives, technological competencies, and integration strategies in STEM-related learning environments (Stohlmann et al., 2012; Kim et al., 2013). For example, while science teachers tend to focus on inquiry and experimentation, early childhood teachers often emphasize play-based exploration, and elementary teachers highlight interdisciplinary connections. Despite these distinctions, comparative analyses across branches remain limited in the literature, which restricts understanding of how disciplinary backgrounds shape attitudes and competencies toward STEM. Therefore, examining the effects of STEM education across different branches of pre-service teachers is essential for designing more effective and context-sensitive teacher preparation programs.

However, in the existing literature, STEM practices in teacher education have predominantly been investigated at a general level, focusing mainly on attitudes or overall perceptions rather than multidimensional outcomes. For instance, several studies have explored pre-service teachers' attitudes toward STEM education and their general motivation (Kartal & Tasdemir, 2021; Thibaut et al., 2018), yet fewer have examined specific domains such as attitudes toward robotics (Altun, 2024; Nugent et al., 2016), interest in astronomy (Burrows et al., 2021), or the development of higher-order thinking skills such as creativity and critical thinking (Han et al., 2015; English, 2017). Furthermore, existing studies rarely distinguish between branches—such as preschool, elementary, and science education—when analyzing the effects of STEM-based interventions (Karataş Aydın & Sipahi, 2023). As a result, the field lacks comprehensive micro-level analyses that can reveal how STEM practices influence teacher competencies differently across subject areas. This gap highlights the need for systematic,

multidimensional research that investigates pre-service teachers' domain-specific attitudes, skills, and perceptions toward STEM applications.

The general purpose of this study is to examine the effects of STEM education approach on pre-service teachers' professional competence and readiness levels. In this context, the effects of applied STEM activities on pre-service teachers' development in different skill areas were evaluated in a holistic manner. The sub-objectives of the research are as follows:

- What is the effect of STEM education on pre-service teachers' critical thinking skills?
- Does STEM education have a significant effect on pre-service teachers' interest in astronomy?
- How does STEM education affect pre-service teachers' attitudes towards robotic technologies?
- What is the effect of STEM education on pre-service teachers' attitudes towards STEM approach ?
- Do these effects differ according to the branches of pre-service teachers?

In this respect, the study aims to reveal with empirical data how effective STEM trainings are in order to train teachers who are compatible with TCEM, productive, open to technology and able to think problem-based.

Method

Research Design

This study was conducted using quantitative research methods, within the scope of quasi-experimental design, with a single group pretest-posttest model (Büyüköztürk, 2017). Within the framework of the model, the development of pre-service teachers on four variables (critical thinking, interest in astronomy, robotics attitude and STEM attitude) were evaluated before and after the implementation. In addition, the long-term effect of STEM education was analyzed with the retention test conducted four weeks after the implementation.

Participants

The sample of the study consists of 20 pre-service teachers studying at Kastamonu University Faculty of Education in the 2021-2022 academic year who have not received STEM education. The participants were determined on the basis of volunteerism, and their grade point averages were also taken into consideration in the selection.

Table 1. Distribution of Participants According to Branches

Branch	n	Average Age	Grade Point Average
Preschool Education	5	25	3,59
Classroom Teaching	7	21	3,41
Science Teacher Education	8	22	3,27

9 of the participants were female and 11 were male. The sample has a balanced distribution in terms of homogeneity.

Although the duration of the intervention was relatively short, literature suggests that even brief, high-intensity STEM experiences can produce measurable changes in cognitive and affective outcomes when they involve active design, reflection, and collaborative inquiry (Margot & Kettler, 2019; Honey et al., 2014). The current study followed a similar intensive model, emphasizing hands-on experimentation and contextual reflection within a condensed period, which likely contributed to the observable development in participants' skills and attitudes.

Implementation Process

The training program was supported by Kastamonu University Scientific Research Projects Coordination Unit. During a total of 24 hours of applied STEM training, theoretical presentations, robotic coding applications, astronomy observations and engineering-based design activities were carried out. The training was conducted by two faculty members and an information technologies teacher. The process was directly observed and controlled by the researcher.

Table 2. STEM Activities and Targeted Skills

Event	Targeted Skills / Attitudes
Tower Design	Engineering thinking, problem solving
Light Pollution Application	Scientific inquiry, environmental awareness
Microscope and Bubble Car	Design thinking, science-technology integration
Tinkercad and 3D Printer	Digital design, production
Astronomy Observation (Aymatik)	Interest in astronomy, ability to observe
Arduino: Smart Trash Can	Coding, robotic attitude, algorithmic thinking
Autonomous Vehicle Coding	Technology literacy, creative solution development

Prior to the main implementation, the training program was piloted with a small group of 12 pre-service science and classroom teachers studying at Kastamonu University. The pilot lasted for two consecutive weeks and included four sessions, each lasting approximately 90 minutes. During the pilot phase, participants were introduced to the same instructional materials and activities planned for the main study. Observations focused on the clarity of the instructions, the sequence and timing of the activities, and participants' engagement levels. Feedback was collected through short reflective forms and debriefing discussions at the end of each session. Based on these observations, minor revisions were made to improve the comprehensibility of the content, ensure smooth transitions between activities, and enhance the overall instructional flow.

Data Collection Tools

In the data collection process, four scales with previously tested validity and reliability were used:

Table 3. Scales used

Scale	Developer(s)	Cronbach's α
Critical Thinking Scale	Kocoglu (2017)	.82
Astronomy Interest Scale	Ertas Kilic & Keles (2017)	.84
STEM Attitude Scale	Gülgün et al. (2017)	.85
Robotics Attitude Scale	Şişman & Küçük (2018)	.88

The validity of the Turkish forms of the scales was ensured with the opinions of field experts and the construct validity was confirmed in previous studies.

Data Analysis

Data were analyzed with SPSS 23.0 program. Pre-test-post-test and post-test-retention test comparisons were evaluated with dependent samples t-test. One-way analysis of variance (ANOVA) was used to analyze the differences according to branches; Tukey HSD test was applied in cases of significant differences.

The applicability of parametric tests was evaluated according to skewness and kurtosis values. For example, skewness = 0.24 and kurtosis = -0.68 in the critical thinking scale, and these values remained within ±1 in the other scales. These findings indicate that the data are normally distributed and suitable for analysis (Tabachnick & Fidell, 2013).

There are no missing observations or outliers in the data set. During the research process, no guiding activities or lessons were conducted outside the application, and external influences were limited. In all analyses, the significance level was set at .05 and the results were reported as mean, standard deviation, t, F and p values.

Since the sample consisted of 20 participants, the assumptions of normality were tested using the Shapiro–Wilk test, skewness–kurtosis coefficients, and Q–Q plots. The results indicated that the data were normally distributed ($p > .05$; skewness and kurtosis values between ±1), justifying the use of parametric tests (Field, 2018; Pallant, 2020). For variables that did not meet normality assumptions, non-parametric alternatives were applied accordingly.

Limitations of the Study

This study is limited in terms of sample size and the findings obtained can only be generalized to pre-service teachers with similar characteristics. The fact that the participants were determined on a voluntary basis may cause sampling bias. In addition, since the measurement tools are self-report based, there is a risk of social desirability bias.

Findings

In this section, the effects of STEM education on pre-service teachers' critical thinking skills, interest in astronomy, attitude towards robotic technologies and general attitudes towards STEM approach were evaluated. In addition, the permanence of the gains obtained, the differences according to the branches and the level of association with daily life in line with the feedback of the pre-service teachers were also analyzed.

Changes in Pre-service Teachers' Scale Scores

The pre-test and post-test mean scores, standard deviations, t-values and p-values of the four variables (critical thinking, interest in astronomy, robotics attitude and STEM attitude) are presented in Table.

Table 4 Pre-Test and Post-Test Statistics of Pre-service teachers

Scale	Pre-Test Mean (SD)	Posttest Mean (SD)	t-value	p-value	Comment
Critical Thinking	102,05 (9,68)	110,30 (8,31)	-2,824	.008	Significant increase
Interest in Astronomy	126,05 (18,23)	133,70 (15,70)	-1,431	.161	Not meaningful
Robotic Attitude	97,65 (13,66)	122,40 (13,47)	-5,780	.000	Significant increase
STEM Attitude	130,65 (14,73)	137,30 (17,41)	-1,304	.200	Not meaningful

Note SD = Standard deviation.

When Table 4 is analyzed, it is seen that pre-service teachers showed significant improvement especially in critical thinking and robotics attitude levels after STEM education. The increases observed in the variables of interest in astronomy and STEM attitude were not statistically significant.

In order to measure the short-term sustainability of the effects of STEM education, a retention test was administered to pre-service teachers four weeks after the implementation. The post-test and retention test averages are shown in Table.

Table 5 Retention Test Results

Scale	Posttest Mean (SD)	Retention Test Mean (SD)	t-value	p-value	Comment
Critical Thinking	110,30 (8,31)	109,80 (8,50)	-0,545	.589	No difference
Interest in Astronomy	133,70 (15,70)	134,10 (16,00)	-0,321	.750	No difference
Robotic Attitude	122,40 (13,47)	121,90 (13,60)	-0,487	.630	No difference
STEM Attitude	137,30 (17,41)	136,90 (17,00)	-0,373	.711	No difference

Note SD = Standard deviation.

The fact that there was no significant difference between the post-test and retention test in all variables shows that the short-term effects of the STEM education can be sustained. Participant feedbacks support this situation; pre-service teachers stated that they were able to associate the concepts they learned with daily life as well as professional life.

"I associated the dustbin project we made with Arduino with the waste management in my own neighborhood. In this way, learning became more meaningful." (S3)

"The sundial activity we designed made me think about the concept of time in a different way. I plan to apply this to my own children." (S5)

The mean scores obtained by pre-service teachers according to their branches are presented in Table 3. A significant difference was found in the variables of interest in astronomy and robotic attitude according to branches ($p < .05$).

Table 6 Mean Values by Branches (Posttest)

Scale	Science	Classroom Teacher.	Preschool	F-value	p-value	Comment
Interest in Astronomy	140,2 (11,3)	128,4 (13,6)	126,1 (12,9)	4,321	.01	Science > others
Robotic Attitude	128,6 (10,8)	120,1 (11,2)	117,8 (13,7)	3,982	.02	Science > others

Note SD = Standard deviation.

The differences according to the branches show that especially pre-service science teachers participated in the practices at a higher level. No significant difference was found in critical thinking and STEM attitude variables.

In the study, statistical analysis was not performed according to gender variable. Although the number of participants was balanced as female (n=18) and male (n=21), this can be considered as one of the limitations of the study.

The findings revealed that STEM education had significant effects on pre-service teachers' critical thinking skills and attitudes towards robotic technologies. The pre-service teachers' levels of associating the learned content with daily life are high and this reflects positively on the retention of learning. The results of the retention test also show that the gains can be maintained for four weeks after the application. While the cross-branch analyses revealed that pre-service science teachers showed higher sensitivity to STEM components; all pre-service teachers stated that they benefited from different dimensions of education.

Discussion and Conclusion

The findings of this study demonstrate that STEM education contributes significantly to the cognitive and affective development of pre-service teachers, particularly in areas such as critical thinking and technological self-efficacy. These results provide empirical support for the theoretical foundation of STEM as a constructivist and design-oriented learning approach that promotes higher-order thinking (Bybee, 2013; Honey et al., 2014). The observed improvement in critical thinking aligns with previous research emphasizing that STEM activities foster analytical reasoning, reflective inquiry, and evidence-based decision-making (Han et al., 2015; English, 2017). This reinforces the argument that STEM is not merely an interdisciplinary framework but also a pedagogical model that nurtures epistemological competence through problem-solving and creativity.

The notable increase in pre-service teachers' attitudes toward robotics indicates the potential of hands-on, technology-mediated environments in enhancing both motivation and professional readiness. Similar results were reported by Margot and Kettler (2019), who found that robotics-integrated STEM education strengthens technology integration skills and pedagogical innovation among pre-service teachers. Likewise, recent studies in Finland and Taiwan (Lin et al., 2020; Yüksel, 2025) revealed that practical, design-based STEM experiences improve teachers' digital literacy and creative confidence. The present study complements these findings by offering a contextual example from Türkiye, showing that experiential robotics applications can meaningfully bridge theory and practice in teacher education.

On the other hand, the absence of significant change in the domains of astronomy interest and general STEM attitude indicates that short-term interventions may not suffice for affective transformation (Ampartzaki & Kalogiannakis, 2016; Doğru & Şeker, 2012; Saçkes et al., 2016). Studies by Kelley and Knowles (2016) and Haatainen et al. (2021) similarly highlight that enduring attitudinal change requires prolonged engagement, multidisciplinary exposure, and socially interactive learning settings. Astronomy-related concepts, which often involve abstract and spatial reasoning, may particularly benefit from the integration of visualization tools and immersive technologies (e.g., AR/VR) to enhance conceptual understanding and sustained curiosity.

The retention findings are noteworthy as they indicate the sustainability of learning outcomes. The absence of decline between post-test and retention scores suggests that learning extended beyond surface knowledge, supporting meaningful learning and internalization (Scardamalia & Bereiter, 2010). This also resonates with constructivist perspectives asserting that long-term retention is reinforced when learners actively relate knowledge to personal and contextual experiences (Fensham, 2022).

When situated within the global context, these findings mirror trends reported in the U.S., Finland, and East Asian countries, where STEM-based teacher education programs increasingly emphasize design thinking, interdisciplinary integration, and reflective practices (OECD, 2023; English, 2017). However, OECD (2022) data show that pre-service teachers in Türkiye still lag behind in digital and critical thinking competencies compared to their international peers. This discrepancy underscores the need to institutionalize holistic, context-based STEM models within teacher education curricula. The proposed model in this study—centered on contextual integrity, hands-on design experience, and reflective assessment—aligns with these international trends and provides a locally adaptable framework for the Turkish Century Education Model (MoNE, 2024).

In summary, this research contributes to the global discussion on STEM education by providing empirical evidence from the Turkish context, confirming that when STEM pedagogy is contextualized and experiential, it can foster both cognitive advancement and affective engagement among pre-service teachers. Future studies should employ longitudinal designs and cross-branch comparisons to better understand the sustained and discipline-specific impacts of STEM education.

Recommendations

This study shows that STEM education improved pre-service teachers' critical thinking skills and attitudes towards robotic technologies. In addition, pre-service teachers' capacity to associate what they learned with daily life improved and their learning processes became meaningful. However, there was no significant development in areas such as interest in astronomy and general STEM attitude. This situation suggests the effect of implementation time, content structure and individual differences.

Based on these findings, the following suggestions can be made:

1. STEM trainings should be provided in a modular, applied and continuous structure in teacher training programs.

2. Abstract content such as astronomy should be supported by visualization, storytelling and simulation.

3. Robotics applications should be structured gradually according to branches; support materials especially for preschool and classroom teachers should be increased.

4. STEM practices should be scaled in different socioeconomic regions to address access and equity issues.

5. In future research, more holistic analyses should be conducted with qualitative data, observation and performance-based evaluations.

As a result, STEM education has a strategic potential in terms of producing solutions to social problems, developing technological literacy and gaining 21st century skills beyond increasing the individual competencies of pre-service teachers. For this reason, STEM approach should be considered not only as a preferred but also as a compulsory structure in teacher education policies.

Conflict of Interest

The authors of this article declare that there is no conflict of interest.

Statement of Publication Ethics

The ethics committe approval for the study was obtained from Kastamonu University Ethics Committee, Document No: 2022-40

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Author Contribution Rate

Author 1: Contributed to the conceptualization of the study, development of the research design, and literature review.

Author 2: Contributed to data collection, implementation of the STEM training process, and writing the methodology section.

Author 3: Contributed to data analysis, preparation of findings, and structuring the discussion section.

Author 4: Contributed to editing, critical revisions of the manuscript, and ensuring publication ethics compliance.

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