STEM Education

STEM Education, 5(5): 882–907
DOI: 10.3934/steme.2025039
Received: 01 February 2025
Revised: 09 June 2025
Accepted: 11 July 2025
Published: 29 July 2025

https://www.aimspress.com/journal/steme

Research article

Developing pre-service elementary teachers' self-efficacy for integrated STEM

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Academic Editor: Feng-Kuang Chiang

Abstract: Education policies consistently emphasize the importance of preparing pre-service teachers (PSTs) with the confidence and competence necessary to effectively deliver Science, Technology, Engineering, and Mathematics (STEM) education. Previous research suggests that the success of these initiatives depends on PSTs' beliefs, knowledge, and understanding of STEM education. Specifically, STEM self-efficacy is a key determinant of their ability to navigate challenges in designing and implementing effective STEM learning experiences. This study aims to understand the evolution of PSTs' self-efficacy for integrated STEM teaching during their participation in a one-semester STEM program. Utilizing a mixed methods approach, the study involved 27 PSTs. Quantitative data were collected using the STEM teaching efficacy beliefs instrument, administered as a pre- and post-test, while qualitative data were obtained from the PSTs' STEM lesson plans and final reflections. The results suggest that the STEM program had a positive impact on PSTs' STEM teaching efficacy beliefs, with teacher guidance, peer collaboration, and constructive feedback proving to be pivotal factors in enhancing their confidence and comprehension in the design of integrated STEM activities. However, limited opportunities for practical implementation restricted the PSTs' ability to refine their lesson plans and realize the full potential of the program. Future STEM education programs should prioritize opportunities for the PSTs to implement and reflect upon their lesson plans, thereby placing a greater emphasis on formative assessment techniques, inclusivity, and open-ended exploration. By addressing these areas, teacher education programs can further enhance the PSTs' knowledge, skills, and self-efficacy, thus ultimately preparing them to deliver high-quality STEM learning experiences.

Keywords: integrated STEM education, pre-service teachers, self-efficacy, STEM courses

1. Introduction

In recent decades, the educational landscape has undergone a remarkable transformation, marked by an increased emphasis on Science, Technology, Engineering, and Mathematics (STEM) education at the K-12 level. This shift reflects a growing recognition of the importance of STEM skills in equipping students to thrive in modern society [1]. The objectives of STEM education include developing STEM literacy, fostering 21st-century competencies, preparing students for the STEM workforce, promoting interdisciplinary connections, and cultivating interest and active participation [2].

In some countries, ongoing reforms in STEM education have led to the adoption of integrated teaching approaches, which is commonly referred to as integrated STEM education [1,3]. Traditionally, science and mathematics have been taught as separate subjects in elementary and secondary education, with education systems predominantly adhering to a single-discipline model [4]. This traditional structure poses significant challenges to implement the interdisciplinary practices central to STEM education, as the integrated nature of the curriculum often conflicts with conventional school frameworks. Beyond curriculum design, additional barriers include constraints related to time, resources, institutional support, and the teachers' beliefs [5,6]. Despite these multifaceted challenges, national and international STEM education policies continue to encourage educators to foster interdisciplinary connections [7]. In Portugal, reflecting the orientation of the European Union (EU) educational policy, curriculum guidelines promote an integrated and interdisciplinary approach to teaching and learning [8]. STEM initiatives in Portugal largely originate from individual school proposals, supported projects from the Ministry of Education, or external contributions by universities, science centres, museums, professional associations, and educational fairs—many of which function independently of schools. Despite national programs and incentives to address STEM education, the curricula make no explicit reference to an integrated STEM approach.

The success of these initiatives is contingent upon the beliefs, knowledge, and understandings that teachers possess regarding STEM education [9]. Among these factors, the teachers' self-efficacy beliefs stand out, as they significantly influence the task performance and expectations of success in implementing innovative teaching practices [10]. In fact, self-efficacy is a strong indicator of a teachers' confidence and skills to teach STEM [11–13] and has an impact on their teaching practice [14]. Teacher education programs play a critical role in preparing future teachers to be more innovative and capable of effectively implementing integrated STEM education [15,16]. Addressing the pressing demand for highly qualified STEM teachers requires offering pre-service teachers (PSTs) opportunities to design and integrate interdisciplinary STEM units as part of their training [17]. These experiences expose the PSTs to effective STEM pedagogical practices, thus preparing them to successfully navigate elementary school contexts. Prior research has shown that an engagement in STEM education enhances the teacher's self-efficacy, which is linked to a greater confidence and an improved ability to deliver STEM instruction [16,18,19]. However, there remains limited understanding of the processes through which the PSTs' self-efficacy for integrated STEM teaching is shaped during their teacher preparation programs [20]—a gap that is particularly pronounced in the context of Portuguese educational research. This study seeks to address this gap by investigating how the PSTs' self-efficacy for integrated STEM teaching evolved during their participation in a STEM program over one semester. Specifically, the study is guided by the following research questions (RQ):

RQ1: What is the impact of a one-semester STEM program on the STEM teaching efficacy beliefs of pre-service elementary teachers?
RQ2: How do pre-service elementary teachers experience STEM program-related tasks?

By addressing these questions, this research aims to contribute valuable insights into the professional development of PSTs. Understanding how teacher education programs influence STEM teaching self-efficacy can guide the design of effective training initiatives, ultimately advancing the implementation of integrated STEM education in elementary classrooms.

2. Theoretical framework

2.1. Integrated STEM education

Despite the recognized importance of integrated STEM education, there is no consensus on its definition or how it should be implemented [3,7]. A review of the literature reveals a number of different conceptualizations of integrated STEM education (e.g., [21–23]). This study is informed by the concept of integrated STEM education, which is defined by Kelley and Knowles [23] as "the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning" (p. 3). Additionally, the authors emphasized that it is not the number of disciplines that are integrated that reflects the degree of integration in a STEM curriculum; rather, it is the connections of the relevant disciplines to the real-world problem and the connections between the disciplines that are important. While most definitions agree that at least two disciplines should be included, determining the precise nature of integration has proven challenging due to differences in how scholars conceptualize the role of each discipline [24].

A substantial body of research has identified a number of challenges and barriers to the implementation of STEM education in elementary classrooms, which include a poor understanding about STEM education among educators [25], deficiencies in both science and mathematics content knowledge that impede teachers' ability to communicate the disciplinary core ideas that are fundamental to an integrated STEM approach [2], and time and curriculum constraints [6]. Due to a lack of confidence, many in-service and PSTs lack STEM role models, as STEM lessons were not part of their own school experiences and are still absent from many classrooms today [26]. In particular, elementary teachers often have limited background knowledge, confidence, and self-efficacy when it comes to teaching STEM subjects [27]. For example, Kurup et al.'s [28] study evidenced that primary PSTs lacked strong understandings of integrated STEM and received limited opportunities to engage with or teach integrated STEM in schools.

Additionally, varying conceptualizations of the integrated STEM approach may further complicate a teachers' efforts to design and implement effective integrated STEM curricula [5]. Another critical barrier is the inadequacy of elementary PST training programs, which often fail to include the courses necessary to develop the skills required for effective STEM instruction [17].

Addressing these barriers necessitates a shift from broad conceptualizations of STEM education toward the establishment of specific frameworks that can inform and structure curricular decisions [29]. While there are no regulations or curriculum documents in Portugal that explicitly define STEM education, the principles that underlie an integrated STEM approach closely align with the interdisciplinary and transdisciplinary integration emphasized in the new elementary and secondary education curricula. The teacher education model in Portugal is currently undergoing reform across all educational levels, thus offering a timely opportunity to integrate the STEM approach.

There are a number of frameworks available in literature to guide the design and implementation of STEM education (e.g., [2,3,29]). Honey et al. [2] proposed a theoretical framework for integrated STEM education that emphasizes the purposeful connection of science, technology, engineering, and mathematics through authentic, interdisciplinary learning experiences. Central to this framework is the idea that STEM education should mirror real-world practices, thereby engaging students in problem-solving, inquiry, and design-based challenges that transcend the individual subject boundaries. The framework promotes STEM literacy, not only in terms of conceptual understanding, but also in terms of applying knowledge to meaningful contexts. It highlights the importance of equity and inclusion, and aims to broaden participation in STEM fields, particularly among underrepresented groups. Moreover, it calls for rethinking teacher preparation and professional development to ensure that educators are equipped to deliver integrated instruction, and it stresses the need for innovative assessments and continued research to evaluate and refine STEM teaching practices. Roehrig et al. [29] developed a conceptual framework that assesses coherence and integration in STEM curriculum units by analyzing 50 real-world examples using a Conceptual Flow Graphic (CFG). This tool identifies how science, mathematics, and engineering design challenges (EDCs) connect within a unit, thereby categorizing them into four types: (1) coherent science units with loosely linked EDCs; (2) engineering-focused units with minimal science integration; (3) EDCs using science as contextual background; and (4) fully integrated, coherent STEM units. The authors demonstrated that engineering practices can function as a contextual integrator within a STEM unit. Additionally, the inclusion of an EDC offers the potential for conceptual integration, as engineering inherently relies on the application of scientific and mathematical knowledge. Integrated STEM curricula that intentionally embed the science and mathematics concepts required students to solve the EDC, where the students engaged in authentic engineering experiences, while also fostering meaningful conceptual connections across disciplines.

This study is informed by the well-defined framework proposed by Thibaut et al. [3], which is comprised of five key principles: *integration of STEM content*, *problem-centered learning*, *inquiry-based learning*, *design-based learning*, *and cooperative learning*. These principles describe the practices that underlie STEM integration. The first principle, *STEM content integration*, refers to the explicit inclusion of learning objectives, subject matter, and pedagogical techniques from different STEM disciplines [3]. It is paramount to make integration explicit and provide students with intentional and explicit support to facilitate the construction of knowledge and skills across disciplinary boundaries [30]. The second principle, *problem-centered learning*, refers to involving students in developing solutions to authentic real-world problems [3]. This has been shown to have a motivational effect on learning, while also providing opportunities for students to draw on their knowledge of a range of STEM disciplines [1]. For these pedagogical strategies to be effective, they need to be student-centered, promote active learning, and connect to the students' lived experiences [31]. This allows students to make connections between the knowledge and skills they are expected to learn and their own personal experiences, thereby promoting meaningful learning [32]. The third principle, *inquiry-based learning* (IBL), is fundamentally regarded as a method of acquiring knowledge through a series of actions that mirror the typical processes employed by scientists in the course of solving problems in real-world situations [33]. Students engage in the role of scientists by planning investigations, critically analyzing data, discussing findings with peers, and developing evidence-based explanations to address the initial questions posed [34]. The fourth principle, *design-based learning* (DBL), places considerable emphasis on the value of engaging in or producing design activities as a means of learning [3]. This pedagogical strategy facilitates the integration of science and mathematics concepts through the utilization of open-ended problem-solving, creative thinking, solution formulation and decision-making, and the examination of alternative solutions to meet diverse constraints [35]. Students are guided to develop prototype models or artefacts that represent a solution to a problem. Finally, the principle of *cooperative learning* posits that students should be afforded the opportunity to engage in communication and collaboration with one another, with a view to enhance their understanding of the subject matter [3].

Several models for restructuring PST preparation programs are increasingly being adopted to enhance the future educators' ability to implement integrated STEM education effectively [15]. These encompass a variety of approaches, including the combination of existing methods courses with the objective of adopting an interdisciplinary approach to STEM teaching and learning, as well as the incorporation of STEM learning opportunities into an existing course [36]. It is of the utmost importance that courses which encompass a multitude of contexts are implemented, with the objective of instilling interdisciplinary knowledge through the use of methodologies that include problem-solving through question formulation, communication, participation in scientific inquiries and engineering, and the design of solutions to complex real-world problems [20]. Few studies in Portugal have focused on the impact of programs on elementary PSTs' knowledge regarding STEM education (e.g., [37,38]). Nonetheless, despite challenges such as a limited mastery of scientific content and an uncertainty in applying effective pedagogical approaches, the findings suggest notable progress in the adoption of a conceptual framework in STEM education, such as the one proposed by Thibaut et al. [3]. These initiatives place well-qualified teachers with high self-efficacy at the forefront of quality STEM education [19].

2.2. Self-efficacy

Teacher beliefs represent a pivotal element of the Social Cognitive Theory, particularly with regard to the concept of self-efficacy [39]. Self-efficacy can be defined as a belief in one's capacity to successfully complete a task within the defined circumstances [39]. It has been identified as a key factor that influences a teacher’s decision-making processes with regard to various aspects of their professional practice, including the design and delivery of instructional activities, lesson organization, and their capacity to effectively respond to challenging situations [39]. According to Bandura [10,40], a teacher’s self-efficacy can be conceptualized as a bidimensional construct comprised of *personal efficacy* and *outcome expectancy*. *Personal efficacy* refers to one's confidence in attaining a specific level of performance and encompasses a teacher’s beliefs in their ability to effectively teach. On the other hand, *outcome expectancy* concerns judgments regarding the probable consequences of specific behaviors and is related to student outcomes as a consequence of their teaching [10].

A self-efficacy scale serves as a professionally and psychologically valuable tool to assess a teacher's beliefs about their ability to teach STEM, thus providing essential evidence to inform the optimal design of STEM teacher training programs [41]. Following this perspective, the present study employs (see 3.4. data collection tools) the Science Teaching Efficacy Belief Instrument for Preservice Teachers (STEBI-B; [42]). Drawing directly on Bandura's self-efficacy theory, Riggs and Enochs [42] argued that the PSTs' beliefs about science teaching and learning were often a limiting factor in their professional development. They emphasized the importance of identifying low self-efficacy early in teacher education programs as a means to better support future teachers. Therefore, the STEBI-B was designed to assess personal teaching efficacy and outcome expectancy specifically in the context of science teaching, thus offering a domain-relevant operationalization of Bandura's bidimensional construct. The purpose of self-efficacy studies, such as those which use the STEBI-B instrument, is to provide valuable insights for teacher educators. These research-based findings enable educators to support elementary PST's in strengthening their self-efficacy and outcome expectancy beliefs, thus ultimately building their capacity to translate these gains into a greater teaching confidence in their future careers [43].

Self-efficacy of in-service and PSTs is a determinant of STEM integration [17,27,44]. Previous studies have suggested a link between a teacher's self-efficacy and their perception of competence and confidence in implementing STEM education [17–19,45]. Specifically, the level of self-efficacy that teachers possess with regard to STEM education may influence their response to challenges that they encounter. For instance, teachers with high self-efficacy are more likely to feel confident and capable of managing the learning environment. Conversely, low self-efficacy among teachers regarding STEM education may result in concerns about the implementation of STEM education and the perception of these tasks as a personal threat [19]. Besides, PSTs with high self-efficacy are more inclined to use inquiry-based practices and create learner-centered environments in their future classrooms [46]. Moreover, the elementary teachers' limited understanding and experience with integrated STEM education have contributed to low levels of teaching efficacy [28]. In this context, and in line with Bandura's definition of self-efficacy, STEM self-efficacy refers to an individual's belief in their ability to effectively implement STEM instruction, which they perceive as enhancing a students' knowledge and understanding of STEM topics [20]. Developing this self-efficacy requires the acquisition of STEM-related knowledge and skills [19].

Research has demonstrated that pedagogical preparation and content knowledge are linked to self-efficacy [47–49]. Because teachers with high self-efficacy in science teaching also tend to possess strong science content knowledge, their self-efficacy can positively impact a students' academic success [47]. Alternatively, elementary teachers often lack confidence in science and math content areas and may be reluctant to teach these subjects. For instance, Cobern and Loving [48] surveyed elementary teachers and found that while the majority felt confident teaching reading and language arts, significantly fewer expressed the same level of confidence in teaching science. Appleton [50] found that beginning teachers with low confidence often avoided hands-on science activities, instead opting for reading- and writing-based strategies. Findings like these have prompted numerous studies aimed at enhancing the science teaching self-efficacy of elementary teachers' education students. Research has shown that science methods courses that incorporate extensive hands-on activities can be highly effective in this respect [51]. In other words, high-quality science coursework can significantly influence the PST's science self-efficacy beliefs [49].

Empirical research consistently indicates that engagement in STEM education enhances the self-efficacy of elementary and high school teachers, thereby fostering a greater confidence and improving their capacity to deliver effective STEM instruction [16,18,19]. For instance, the study by Dökme and Koyunku Ünlü [19] evaluated the effectiveness of a professional development program that integrated the skills-based science, technology, engineering and mathematics model (SBSTEM-M) on the self-efficacy of PSTs. The findings showed that the intervention process enabled the development of original STEM activity sets aligned with SB-STEM-M by the PSTs, while also enhancing their STEM self-efficacy. Similarly, Menon et al. [20] investigated changes in the PSTs' conceptions of STEM and STEM teaching self-efficacy during their participation in the redesigned STEM semester. The results provided evidence of positive changes in the PSTs' self-efficacy and attitudes towards integrated STEM after their participation in the STEM semester; additionally, it suggested the importance of explicit STEM education in an integrated manner, as opposed to the traditional silo approach. Another study conducted by Johnson et al. [18] investigated the self-efficacy of PSTs for integrated STEM teaching. The results showed that modeling the integrated STEM instruction improved the PST's perceived self-efficacy in teaching science and mathematics within an integrated STEM framework. Still, the PSTs expressed concerns about their content knowledge in science and mathematics, which emerged as a significant limiting factor in the development of self-efficacy.

The findings of these studies indicate that mastery experience, including first-hand teaching experience, has emerged as a particularly influential source of self-efficacy. According to Bandura [10,40], *mastery experiences*, which encompass the successful completion of tasks, serve as a pivotal catalyst for psychological transformation. Such experiences not only influence the initiation of new coping behaviors but also influence their persistence. Furthermore, individuals are more inclined to undertake novel challenges if they have previously experienced success in analogous circumstances, which serves to augment self-efficacy. However, Bandura [10,40] identified other sources of self-efficacy, namely *vicarious experiences, verbal persuasion, and emotional and physiological states*. *Vicarious experiences* occur when individuals observe others successfully performing tasks, thereby enabling them to form beliefs about their own ability to successfully appropriate that set of behaviors. For example, Radloff and Guzey [52] demonstrated that PSTs who watched and reflected on expert videos of integrated STEM practices developed more positive conceptions of STEM teaching, thus suggesting the potential of such media as powerful vicarious experiences. Similarly, *verbal persuasion* refers to positive or negative feedback received from peers, colleagues, or the environment regarding one's capabilities and task performance. This feedback can significantly influence an individual's confidence in their abilities [39]. Within STEM teacher preparation, structured opportunities to provide and receive feedback appear particularly valuable. For instance, Dökme and Koyunku Ünlü [19] found that when PSTs critically reflected on the mistakes and limitations in their peers' teaching activities, they not only avoided similar errors themselves but also reported increased perceptions of STEM self-efficacy. *Emotional and physiological states* also affect self-efficacy, as these reactions influence how individuals perceive their competence. Positive emotional arousal during teaching can enhance self-efficacy, whereas negative states, such as stress, anxiety, or worry, can undermine it. In fact, negative physiological reactions have been shown to impede performance, thus potentially leading to a reduced sense of competence and an inability to successfully perform [39]. Wu and Albion [53] found that a PSTs limited experience in STEM education may lead to avoidance or a superficial integration of STEM practices, often triggered by anxiety.

Recent meta-analyses provided strong evidence on how a PST's self-efficacy can be effectively supported through targeted interventions during teacher preparation. Täschner et al. [54] analyzed data from 115 studies and found a moderate overall effect of interventions on the PSTs' self-efficacy, with the most substantial gains observed in interventions exclusively focused on mastery experiences. Notably, the inclusion of reflective components was also recommended to enhance outcomes. Similarly, in a meta-analysis of 28 studies, Mok et al. [55] highlighted the effectiveness of individualized support activities such as modelling, feedback on lesson plans, and reflection. Among these, feedback on lesson planning was especially impactful in strengthening self-efficacy, even when accounting for other factors such as mastery experiences.

It can consequently be argued that the development of STEM self-efficacy is contingent upon a combination of these evidence-based strategies, with a particular emphasis on direct experiences, wherein PSTs deploy a range of strategies and rules to achieve success [17]. Therefore, it is imperative that teacher preparation programs provide PSTs with a comprehensive range of opportunities—not only to design and implement STEM activities, but also to observe effective role models, engage in guided reflection, and receive consistent, constructive feedback. Addressing these multiple sources of self-efficacy in a holistic and intentional manner is essential to cultivate a robust sense of STEM teaching efficacy. Ultimately, this will better equip PSTs to navigate the complexities of integrated STEM instruction with both confidence and competence.

3. Methods

3.1. Design

The study employs an embedded mixed-methods design, thereby utilizing both quantitative and qualitative research techniques for data collection, where the data are integrated and subjected to analysis [56]. The quantitative data set examined the evolution of the PSTs' STEM teaching self-efficacy beliefs, whereas the qualitative data set explored their experiences throughout the STEM program. The research pattern is illustrated in Figure 1.

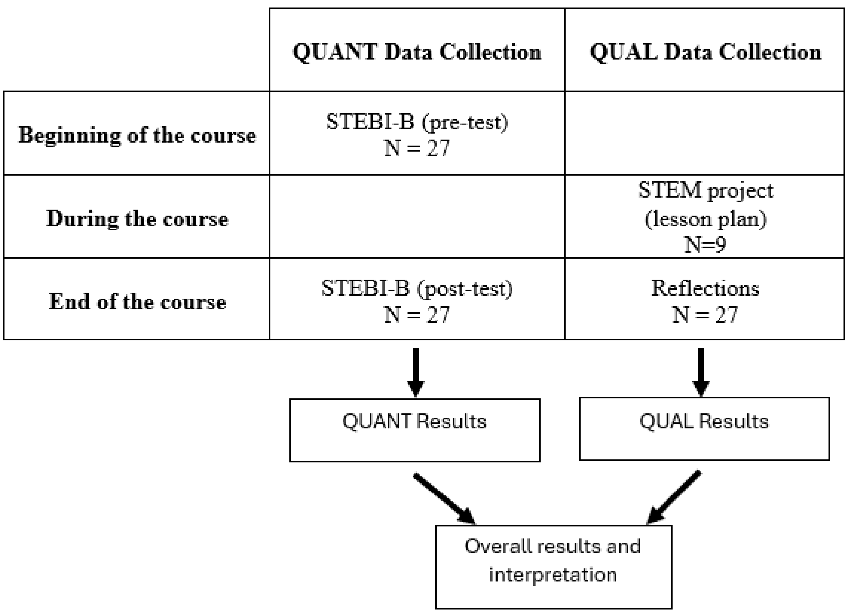

Figure 1. Research patterns.

3.2. Participants

A total of 27 PSTs enrolled in the final year of the teacher education program (a three-year bachelor's degree) at a Portuguese higher education institution participated in the research project. These participants were purposively selected, as they constituted the only cohort of graduating students attending the Science Methods course during the data collection period. The sample was exclusively female, thus reflecting the demographic profile of this specific program. The absence of male participants is due to the fact that no male students were enrolled in the course at the time of the study. The participants had an average age of 21.6 years (SD = 1.82), and none had prior teaching experience before enrolling in the program. The program consists of a three-year bachelor's degree, which must be followed by a two-year master's degree in a specific teaching domain (e.g., Teaching of Science and Mathematics in Basic Education – 2nd cycle) in order for the graduates to become fully qualified teachers in Portugal. By their final year, the PSTs had completed coursework in teaching principles, pedagogical content knowledge, and educational technologies. In accordance with ethical considerations, the names of the PSTs and other related information have been omitted from the study. Instead, they were assigned numerical codes, with PST1, PST2, and so on up to PST27. Participation in the study was on a voluntary basis, with the option for the participants to withdraw at any point. In all classes, the PSTs collaborated in self-selected groups of three or four.

3.3. STEM program

The PSTs were introduced to the topics listed in Table 1 during the 12-week Science Methods course, which lasted over 24 hours (2 hours per week), with an emphasis on the five characteristics of the integrated STEM education model proposed by Thibaut et al. [3].

Table 1. Topics covered in the Science Methods course.

Topics
Science curriculum in elementary education
The benefits of science education in elementary education
Social constructivism in science education
Development of 21st-century skills
Problem and project-based learning
Hands-on activities
Inquiry-based learning
5E-instructional model [57]
Integration of technology
STEM education

In the first part of the program, the PSTs engaged in various STEM activities, analyzed the underlying instructional practices, evaluated teaching materials, and identified the corresponding science curriculum topics. During the second half, they developed STEM lesson plans, exchanged and refined ideas by presenting their STEM materials to peers, and reflected on both the opportunities and challenges of implementing an integrated STEM approach. Some of PSTs had the opportunity to perform STEM activities during two weeks of teaching practice.

3.4. Data collection tools

3.4.1. STEM teaching efficacy beliefs instrument

In order to ascertain the STEM teaching efficacy beliefs of the PSTs, the STEBI-B was adapted for use in this study. The STEBI-B is a well-established instrument that was developed and validated by Riggs and Enochs [42], and translated versions of the instrument have been used in a number of studies internationally (e.g., [58]). Although other instruments such as the Teachers' Sense of Efficacy Scale (TSES; [59]) have gained widespread use in studies on teacher beliefs [60], their domain-general nature poses limitations when investigating STEM-specific efficacy beliefs. The TSES assesses broad teaching competencies—namely classroom management, instructional strategies, and student engagement—which are not directly aligned with the objectives of the present study. In contrast, the STEBI-B was explicitly developed within Bandura's self-efficacy theory to measure efficacy beliefs related to science teaching, thus enabling a more focused adaptation to the STEM context. Considering the goal of effectively evaluating the PSTs' STEM teaching efficacy beliefs after completing a STEM program, the STEBI-B was deemed a theoretically sound and contextually appropriate instrument to capture these beliefs.

To align with a broader focus on STEM, the items were revised to read "STEM" in place of "Science" in the survey (e.g., "Increased teacher effort in teaching science produces little change in some students' science achievement" was modified to "Increased teacher effort in teaching STEM content produces little change in some students' STEM learning achievement"). This modification has been demonstrated to be reliable [17,45].

The STEBI-B is comprised of 23 items, which are rated on a 5-point Likert scale, ranging from "strongly disagree" to "strongly agree". The instrument consits of two subscales: the Personal STEM Teaching Efficacy (PSTE) and the STEM Teaching Outcome Expectancy (STOE) subscales. The PSTE subscale is comprised of 13 items and was designed to assess the beliefs that individuals hold about their ability to teach STEM. The STOE subscale is comprised of 10 items and was employed to ascertain the impact of STEM teaching on elementary student outcomes. The instrument employs a combination of forward and reverse-phrased items, with their associated scores being reversed in accordance with the STEBI-B implementation guidelines.

The initial version of the survey instrument was translated into Portuguese. To guarantee that the survey could be read and understood, three PTSs were invited to complete the survey and provide feedback on the instructions, question format, and wording. In light of the feedback provided, further refinements were made to the survey prior to its finalization and administration to the participants. Factor analysis procedures were employed to substantiate the reliability of the survey instrument within the context of this study. The reliability of the STEBI-B was satisfactory (Cronbach's α = 0.80), with the same evaluation being achieved in both subscales (Cronbach's α (PSTE) = 0.79; Cronbach's α (STOE) = 0.86). These values exceed the threshold of 0.70, which is considered acceptable [61].

The STEM teaching efficacy beliefs were gauged through the administration of a pre- and post-test questionnaire to the PSTs prior to (September 2023) and following (January 2024) the completion of the course. The questionnaire was administered in person under the supervision of the researchers. Prior to the administration of the questionnaire, the participants were provided with a brief description of the purpose of the study and an informed consent process. The completion of the questionnaire took approximately 10 minutes. The pre- and post-tests were matched using the PSTs' identification numbers.

3.4.2. Lesson plans and PST's reflections

During the PSTs' attendance at the science methods course, they engaged in a collaborative planning process for a single STEM activity (lesson plans). In addition to the lesson plans, the PSTs were invited to participate in a reflective exercise at the conclusion of the semester, which aimed to analyze their experiences in designing STEM activities. This exercise provided an opportunity for the PSTs to critically reflect on their STEM-related experiences and articulate how these experiences influenced their growth as learners and prospective teachers of integrated STEM.

3.5. Data analysis

The quantitative data were subjected to analysis using the Jamovi®, 2.2.5.0, software package. The reliability of the survey and its subscales were evaluated through the calculation of Cronbach's alpha (α). Descriptive statistics were examined, and the mean score was obtained for the survey and for each subscale. The normality assumption of the data was evaluated through the application of the Shapiro-Wilk test. A pre-post repeated measures design was employed to ascertain the alteration in STEM teaching efficacy beliefs for the PSTs ($n = 27$) between the pre- and post-tests (two time points). The t-statistic was employed to test the null hypothesis that no significant differences existed between the pre- and post-self-efficacy mean scores for the STEBI-B (total) and its subscales. Furthermore, Cohen's D was utilized to estimate the effect size, thereby providing information regarding the magnitude of the change from pre- to post-test. The statistical analyses used a confidence level of 95% ($p < 0.05$).

The qualitative data were subjected to a content analysis, thereby employing a mixed deductive-inductive method. In the analysis of the PSTs' planned STEM activities, the predetermined categories, adapted from Thibaut et al. [3], were utilized. The analysis of the PSTs' reflections was conducted utilizing a mixed deductive-inductive method, drawing upon Bandura's [10,40] sources of self-efficacy and adhering to Bengtsson's [62] four-phase framework. Prior to the independent coding process, the two researchers engaged in a calibration session to discuss the framework's dimensions and clarify the coding criteria. Then, the coding process was carried out independently, with the PSTs' comments systematically highlighted and assigned initial codes. Subsequently, the data were categorized based on their collective meaning, and the coded data were rearranged into more refined categories. After this stage, the researchers compared their coding results and resolved any discrepancies through discussion until a full agreement was reached, thereby ensuring consistency and enhancing the trustworthiness of the analysis. Finally, the resulting categories were reviewed and refined to ensure accuracy and relevance. In order to ensure credibility, direct quotations of the PSTs' comments have been included in the results section.

4. Results

4.1. STEM teaching efficacy beliefs

The study examines changes in the PSTs' STEM teaching self-efficacy beliefs after participating in a one-semester STEM program. Table 2 presents the descriptive statistics for the pre- and post-STEBI-B (total) and its subscales (PSTE and STOE).

Table 2. Descriptive statistics for the pre- and post-STEBI-B and its subscales (N = 27).

						Shapiro-Wilk	
STEBI-B	Subscale	Mean	SD	Min	Max	W	p
	PSTE	3.36	0.49	2.69	4.46	0.949	0.207
Pre-Test	STOE	3.44	0.66	1.50	4.88	0.933	0.083
	Total	3.39	0.39	2.57	4.24	0.975	0.744
	PSTE	3.67	0.64	2.31	4.85	0.981	0.894
Post-Test	STOE	3.57	0.44	2.88	4.50	0.949	0.198
	Total	3.63	0.45	2.81	4.43	0.931	0.072

A paired sample t-test was employed to ascertain the differences between the pre- and post-STEBI-B survey results (Table 3). The analysis revealed a statistically significant increase in the mean scores for the STEBI-B (total) and PSTE subscale when comparing the pre- and post-test data.

Table 3. Paired samples t-test results for comparison of STEBI-B and its subscales (STOE and PSTE).

STEBI-B	Subscale	t	p	Effect size
Pre-test – Post-test	PSTE	-2.368	0.026*	-0.456
	STOE	-0.868	0.394	---
	Total	-2.905	0.007*	-0.559

A significant difference was observed in the mean score of STEBI-B from the pre-test (M = 3.39, SD = 0.39) to the post-test (M = 3.63, SD = 0.45); $t_{(26)} = -2.90$, ($p = 0.007$). Furthermore, the PSTE subscale mean scores demonstrated a statistically significant difference between the pre-test (M = 3.36, SD = 0.49) and post-test (M = 3.67, SD = 0.64) phases; $t_{(26)} = -2.37$, ($p = 0.026$). These findings suggest that pre-service teachers who engaged in a one-semester STEM program tended to enhance their STEM teaching efficacy beliefs, particularly their personal STEM teaching efficacy.

4.2. Lesson plans

The results obtained from the analysis of the PSTs' lesson plans were summarized in accordance with the predetermined categories from Thibaut et al. [3], as illustrated in Table 4.

Table 4. Instructional practices evidenced in the PSTs' lesson plans.

Lesson plan	Category				
	STEM content integration	Problem-centred learning	Inquiry-based learning	Design-based learning	Cooperative learning
1	x	x	x	x	x
2	x		x	x	x
3	x				x
4	x			x	x
5	x				x
6	x			x	x
7	x				x

The activity proposed by Group 1, titled "In the Flavour of the Wind," aims to deepen a students' understanding of sailing cars and the factors that affect their movement through space. This activity integrates science and mathematics curriculum content, specifically the themes of "forces" and "geometry and measurement," thus ensuring a balanced approach to both subjects. Additionally, the lesson plan incorporates objectives from mathematics, science, technology, and visual arts. The activity follows the 5E instructional model (Engage, Explore, Explain, Elaborate, and Evaluate) [57]. In the Engage phase, the students are introduced to the topic through a technology-enhanced video that captures their interest and introduces fundamental concepts. However, in this phase, technology primarily serves as a supportive resource. The Explore phase involves hands-on learning as the students construct a model of a sailing car. This is followed by the Explain phase, where the students conduct a simple experiment to investigate the relationship between the sail size (varied surface areas) and the distance traveled by the car. During the Elaborate phase, the students present their work to the class, where they explain the processes they followed and the outcomes they achieved. Finally, in the Evaluate phase, the students reflect on the activity by responding to questions about what they enjoyed, the challenges they faced, the knowledge they gained, potential improvements to the activity, and their overall performance. The activity engages students in group work, thereby immersing them in authentic, open-ended experiences that address real-world problems and design challenges.

Group 2's lesson plan centers on constructing a paper and cardboard automaton to raise the students' awareness of the causes and consequences of deforestation. The activity integrates concepts from STEM and the arts, with clearly defined learning objectives for each discipline outlined in the lesson plan. The activity begins with a guiding problem: Can a paper automaton help raise awareness about the environmental impact of human actions? The construction of an automaton as a medium for awareness is an innovative approach that blends both engineering and artistic problem-solving, thus making the activity purposeful. However, the phrasing of this question may not be sufficiently engaging to foster active and hands-on learning. To provide context, the students watch a video on the causes and consequences of deforestation. During the construction phase, the students create an automaton in group, featuring a lumberjack in a forest setting. This task incorporates measuring lengths, understanding angles, and exploring the mechanics of gears, levers, and links, as well as how these components influence the automaton’s movement. In the testing phase, the students are required to examine how variations in the speed applied to the automaton affect the lumberjack's motion. Inquiry-based learning could be expanded through open-ended exploration, thus encouraging students to hypothesize, test different mechanisms, and collect and analyze data, rather than merely observing the impact of variations in speed on the automaton's movement.

The lesson plan for Group 3 includes a field trip to the city of Santarém, Portugal, aimed at enhancing the students’ geographical orientation skills while fostering an appreciation for the city’s cultural heritage. During the visit, the students observe various monuments and use technology such as GPS devices and stopwatches to measure distances and travel times. After collecting this data, the students draw their route on a map, marking key stops along the way. In the final phase, they complete tasks related to their route, such as identifying historical landmarks, comparing walking and driving routes, and solving mathematical problems that involve distance measurements. The tasks were designed to be completed in groups. While the lesson plan references some science learning objectives, these are less prominent compared to the focus on mathematics and technology. The field trip provides an authentic learning experience, as it connects students to real-world geographical and historical contexts. The use of GPS devices and stopwatches makes the activity feel relevant to modern technology applications. However, the authenticity could be enhanced by incorporating real-world problems that involve more complex data collection or analyses, such as optimizing a route for environmental sustainability (e.g., minimizing fuel consumption or walkable distances). This could make the activity even more relevant to the students' lives and future problem-solving scenarios.

The lesson plan for Group 4 involves students in an activity that focuses on rainwater reuse, with the aim of making them aware of the importance of water and its management. The lesson plan identifies learning objectives in mathematics and science, and although it includes a design challenge, this is not highlighted. No problem questions were included in the structuring of the activity. The inclusion of a driving question could further guide students' exploration. The activity is divided into three parts. First, the students watch a video on the topic and are given a fictitious amount of money and a list of materials available for a rainwater harvesting project and their prices. The integration of technology could be expanded by incorporating digital tools or simulations to model water flow, storage capacity, or budget optimization. Then, the students are tasked with designing a rainwater harvesting circuit to be installed in a house (a model is provided by the teacher), drawing up a budget for the materials required, and efficiently managing the money to purchase them. Finally, the students are required to implement their project, test it, and discuss possible improvements. The activity emphasizes the engineering design process (design, build, test, improve), thus helping the students to understand how to create practical solutions for real-world problems. Linking the activity to larger-scale applications, such as urban water management systems, can contextualize the project within broader STEM themes.

The activity proposed by Group 5 explores various service domains and their functions using robotics. The activity aims to promote the development of spatial and mathematical skills. While the lesson plan includes objectives related to mathematics, science, and Portuguese, the emphasis is primarily on mathematics, with no explicit learning objectives for technology despite the inclusion of robots. The activity is divided into three stages. The concept of services are introduced, with the showing of a video and group dynamics, such as grouping cards with pictures of different services, and creating simple itineraries based on the services presented. Later, a practical exploration of mathematical content related to everyday life is planned, such as calculating the costs and solving problems related to time and space. Finally, the learning is consolidated through a practical activity using the DOC educational robot (Clementoni®) and a board created for the activity. The student's are divided into groups, given a script with a story about the daily life of a family, and each group programs the robot to complete routes related to a character in the story. Along the way, they solve challenges related to science and mathematics. By using a board game with a robotic element, students simulate real-world navigation and problem-solving, which connects to everyday experiences such as planning routes and organizing information. However, the task is somewhat abstract, and focuses more on structured gameplay than on solving open-ended problems rooted in real-world challenges. Additionally, the use of the DOC robot introduces a technological dimension, although it serves more as a tool for movement than as a focal point for technological exploration or problem-solving.

The lesson plan developed by Group 6 involves building a greenhouse to help the students learn about its function and operation. While the objectives for mathematics and science are delineated, no explicit objectives for engineering and technology are identified. The activity is not initiated by a problematizing question and is comprised of three distinct stages. First, there is a field trip to the Estufa Fria in Lisbon (botanical garden in a greenhouse), which focuses on understanding the purpose and function of greenhouses. Next, the classroom activities include completing a worksheet about the visit, watching a video about the greenhouse effect, and building a model of the greenhouse. Finally, the constructed greenhouses are presented, thus highlighting the knowledge acquired and the practical challenges encountered. The activity encourages observation (via the field trip), hypothesis formulation (concerning the function of greenhouses), and experimentation (building their greenhouse models). However, opportunities for open-ended exploration (e.g., varying designs or materials) could enhance the inquiry dimension. Additionally, the activity could benefit from a more explicit focus on the engineering design cycle, including the incorporation of iterative design. The students are encouraged to design, build, test and refine their model based on performance or new insights, a process which mirrors real-world engineering processes.

Group 7's proposed lesson plan, entitled 'Smoking', aims to explore the effects of smoking on the human body, develop critical health awareness, and stimulate mathematical skills related to data collection and analysis. Although the lesson plan is designed to cover science and mathematics objectives, it incorporates technological resources such as Canva and Excel into the activities; however, no explicit learning objectives related to technology are identified. The lesson plan consists of three activities. The first activity is an experiment that demonstrates the harmful effects of tobacco through a practical simulation using simple materials such as cigarettes, plastic bottles, and cotton wool. The second activity involves the creation of digital awareness posters using the Canva platform to promote a life without tobacco. Finally, in Activity 3, the students are tasked with collecting data on the number of family members who smoke, organizing it in tables and bar charts in Excel, and carrying out a statistical analysis. The topic of smoking is particularly relevant as it connects academic learning to pressing real-world health concerns. The *Smoking Bottle* activity engages the students in hands-on experimentation and critical thinking; however, its reliance on a pre-defined script limits investigative autonomy. Allowing students to modify the experiment — such as testing different cigarette types or exploring alternative filtering materials — could expand the inquiry and deepen their understanding.

4.3. PST's reflections

The results obtained from the content analysis of the PSTs' reflections were summarized in accordance with Bandura's [10,40] sources of self-efficacy, as illustrated in Table 5.

Table 5. Subcategories of sources of self-efficacy derived from the PSTs' reflections.

Sources of self-efficacy	Subcategories	Quotations
mastery experiences	Understanding STEAM/STEM	- By creating the lesson plan, we were able to better understand the idea of STEM activities and how this approach can be used in the classroom (G1AB). - We learned how to combine maths and environmental studies to create

		meaningful learning (G3MB). - I learned more about interdisciplinarity by thinking about how all subjects are connected in lesson planning (G4AR).
	Professional skills development	- I could develop skills like critical thinking, creativity, resilience and confidence (G1AB). -This work not only broadened our understanding of interdisciplinary education but also strengthened our competencies as future educators (G4AR). - I feel that I have developed in terms of my scientific knowledge and as a future teacher (G5BV).
Vicarious experiences	Inspiring examples	- We used one of the scripts provided by teacher M.C. as a model and adapted it to our activity (G1AB). - We got the idea from STEM activities we had seen before and from the teachers' ongoing support (G2NC). - We based it on an activity we saw on a field trip, and getting in touch with this activity helped us to understand what a STEM activity is (G4RC).
	Collaboration as a source of learning	- We've had our difficulties in doing this work, but we've overcome them as a group, and everyone's ideas have helped us to do it in a way that we're proud of (G2RC). - The complexity of constructing this lesson plan helped me to value teamwork (G2AA). - The feedback from the other groups was helpful in designing this type of activity (G5TB).
verbal persuasion	Teacher guidance	- The teachers' feedback was essential in guiding our learning and choices (G2FB). - The teachers helped us to clarify the language and suggest activities appropriate to the level of teaching (G3RC). -The tasks carried out at the request of the teachers were fundamental to the final work (G6RC).
Emotional and physiological states	Anxiety	- At first I found it difficult to understand the concept of interdisciplinarity (G3MB). -At first, we really struggled to know how to do a STEM activity (G4RC). - At first, it was hard to find a theme that could combine different subjects (G6GV).
	Overcoming	- It's been a stimulating and enriching experience, as I now have the necessary foundations to carry out a similar activity in the future (G1LM). - It was a big challenge, but important for our growth (G3MC). - I learned something that's going to be useful for me in the future (G5CS).

Mastery experiences are often highlighted in the reflections, thus showcasing achievements in *understanding the concept of STEM activities*, designing interdisciplinary tasks, recognizing the practical impact of these activities, and acquiring essential *teaching competences*. The existence of validation moments with the teachers and children during practical implementation (in some cases) not only facilitated a deeper understanding of the STEM concept but also reinforced its importance in education. Furthermore, the success experienced during the process of creating and implementing STEM activities appears to have had a positive effect on the PSTs' confidence in their ability to carry out challenging interdisciplinary work.

The primary sources of vicarious learning were ascertained to be observational studies of practical *examples* and *collaborative work*. Numerous groups reported being inspired by prior activities and interactions with peers to surmount obstacles. This assistance appeared to foster the PSTs' confidence in their capabilities during the planning of the STEM activity.

The provision of support and positive feedback from teachers was often highlighted as a factor that helped the groups to overcome challenges and maintain motivation. Verbal persuasion, facilitated by *teacher guidance* and positive feedback, appears to have been a key factor in enhancing confidence throughout the process, particularly during periods of doubt and difficulty. This approach has been shown to facilitate the overcoming of emotional barriers and the validation of efforts, thereby promoting resilience and progress.

The reflections from the groups reveal a clear progression in their emotional and physiological states throughout the process of planning a STEM activity. Initially, many PSTs experienced *anxiety* and doubt, which largely stemmed from a limited understanding of STEM activities and the challenges of interdisciplinary integration. However, these initial struggles were gradually mitigated through collaborative efforts and the support provided during the process. By the end, the groups expressed *pride and satisfaction in their accomplishments*, along with an increased motivation and self-confidence in both the applicability of their planned activities and their ability to tackle future challenges. This emotional progression observed suggests the positive impact of the experience on the PSTs' personal and professional growth, as well as their confidence in implementing STEM activities in their future teaching practices.

5. Discussion

The present study focused on two main objectives: (1) to assess the impact of a one-semester STEM program on the STEM teaching efficacy beliefs of pre-service elementary teachers; and (2) to understand how pre-service elementary teachers experienced the STEM program-related tasks.

The results revealed a significant increase in STEM teaching efficacy beliefs when comparing the pre- and post-test data. This result suggests that the PSTs who engaged in a one-semester STEM program tended to enhance their STEM teaching efficacy beliefs, particularly their personal STEM teaching efficacy. This finding is consistent with the results of previous research, which demonstrated that engagement in STEM education increases teacher self-efficacy [18–20]

The analysis of the PSTs' reflections helps to understand the factors that have contributed to the evolution of the PSTs' STEM teaching efficacy beliefs. Initially, the PSTs reported feelings of *anxiety* and doubt, primarily due to their limited understanding of STEM activities and the complexities of interdisciplinary integration. During the first phase of the STEM training program, the PSTs were involved in a detailed analysis of various STEM activities, which examined their instructional practices and associated teaching materials. However, this analysis alone proved insufficient for the PSTs to fully grasp the concept of STEM activities or gain the confidence needed to plan them. This result highlights that the development of STEM self-efficacy is highly dependent on hands-on experiences, where the PSTs actively implement strategies and rules to achieve success [17,63]. Throughout the planning process of the STEM activities, the initial emotional barriers faced by the PSTs were progressively alleviated through *collaborative efforts* and *teacher guidance*. Validation moments involving teachers, peers, and children also played a crucial role in supporting the PSTs' confidence in their abilities. As emphasized by Dökme and Koyunlu Ünlü [19], feedback facilitates the development of mastery and vicarious experiences, which are instrumental in strengthening the PSTs' sense of self-efficacy. Specifically, mastery experiences serve as a pivotal catalyst for psychological transformation [10,63]. By the conclusion of the program, the PSTs expressed pride and satisfaction in their achievements. Additionally, they described an increased motivation and confidence in implementing their planned activities and in handling future teaching challenges. The observed emotional progression suggests the positive impact of the STEM activity's planning process on the PSTs' personal and professional growth, as well as their confidence in implementing STEM activities in their future teaching practices. These results are similar to those of Menon et al. [20], who evidenced positive changes in the PSTs' self-efficacy and attitudes towards integrated STEM after their participation in the STEM semester.

Developing STEM self-efficacy requires the acquisition of STEM-related knowledge and skills [19]. The PSTs' reflection often highlighted mastery experiences, thereby showing achievements in *understanding the concept of STEM activities*, designing interdisciplinary tasks, recognizing the practical impact of these activities, and *acquiring essential teaching skills*. In this context, an analysis of the lesson plans developed by the PSTs offers valuable insights into their level of comprehension of STEM activities. In general, the lesson plans demonstrated a concerted effort to integrate content from multiple STEM disciplines, thus providing students with valuable interdisciplinary experiences. However, some lesson plans lacked clear objectives for engineering and technology, even when these components were present in the activities. For example, some activities used technology such as the DOC robot, GPS, Canva, and Excel, thereby extending the possibilities for digital exploration and data analysis and contributing to the development of technological and creative skills. Activities such as constructing wind-powered cars, paper automatons, and investigating greenhouses exemplified creativity and demonstrated the capacity to engage students in active learning. Many of these activities were contextualized within real-world problems, including deforestation, rainwater reuse, and the harmful effects of smoking, thus encouraging students to reflect on issues relevant to their lives and communities. Nevertheless, the integration of sustainable solutions and social impact could be strengthened, as could opportunities for open-ended exploration. Some activities relied on structured scripts, which limited the students' autonomy in conducting investigations. All lesson plans promoted group work, thus encouraging the development of social and collaborative skills. However, few included clear criteria to assess the STEM competencies. Formative assessment tools, such as rubrics or self-assessments aligned with learning objectives, were largely absent. Furthermore, not all activities accounted for the diversity of students in terms of learning styles or access to resources, indicating a need for greater inclusivity and adaptability in lesson design.

As noted in previous research, many PSTs may face challenges in designing STEM activities within a single semester, especially when methods courses represent their first formal introduction to integrated STEM teaching and learning [20]. Nevertheless, the analysis of the PSTs lesson plans revealed significant progress in their understanding of integrated STEM activities. It is important to acknowledge that not all groups had the opportunity to implement the planned STEM activities. This lack of practical experience, combined with limited teaching practice, may explain some of the weaknesses identified in the lesson plans. One prominent weakness, as highlighted in other studies, pertains to the assessment of the students' learning. For instance, Johnson et al. [18] suggested that the PSTs require specific guidance on assessment strategies and called for further research into how the PSTs incorporate assessments into integrated STEM instruction. Additionally, the lack of practical implementation experience and the absence of direct feedback from students might account for the minimal change observed in the PSTs' beliefs regarding the impact of their teaching, as reflected in the STOE subscale. Without concrete evidence that their teaching contributes to the students' understanding of STEM concepts, PSTs may struggle to internalize the belief that their instructional efforts lead to meaningful learning outcomes. This result is further substantiated by research undertaken by Fenton and Essler-Petty [17]. In their study, the PSTs were provided with the opportunity to acquire experience in the design and implementation of robotics and interdisciplinary units in the classroom as part of a combined mathematics and science pedagogy course on STEM integration. Following a single semester, the PSTs exhibited significant positive changes in their self-efficacy and outcome expectancy with regard to STEM teaching. These insights suggest that incorporating authentic teaching opportunities and mechanisms to receive student feedback into teacher education programs may be essential to support the development of the PSTs' STEM teaching outcome expectancy.

The practical application of the lesson plan could enable the PSTs to receive direct feedback from students, thus facilitating the identification of any weak points in the design (e.g., unclear instructions, inadequate materials or steps that did not facilitate the expected learning). Moreover, implementing lesson plans could help the PSTs evaluate whether the activity design is inclusive and responsive to diverse learning styles or specific student needs. A post-implementation reflection is another essential strategy to consider, as it fosters a continuous cycle of improvement in the design of STEM activities. Through iterative reflection, the PSTs would understand that activity design is a dynamic process that can and should be refined based on experience. Engaging in this reflective practice could help the PSTs develop a stronger sense of confidence in designing meaningful, challenging, and adaptable STEM activities, thus ultimately contributing to their STEM self-efficacy.

6. Conclusions

The present study aims to contribute to the existing body of knowledge by exploring how teacher education programs influence the STEM teaching efficacy beliefs of PSTs. The study highlights the positive impact of a one-semester STEM program in fostering the STEM teaching efficacy beliefs of PSTs. Through active engagement in STEM program-related tasks, the PSTs not only gained confidence in their abilities but also demonstrated meaningful progress in their understanding of integrated STEM activities planning. Teacher guidance, peer collaboration, and constructive feedback were identified as key contributors to this progress. Furthermore, mastery experiences played a pivotal role in reinforcing their confidence and professional skills.

Nevertheless, the minimal opportunities for practical implementation limited the PSTs' ability to refine their lesson plans and realize the full potential of the program. This may have led to a prevailing sense of uncertainty among the PSTs about their ability to influence student learning outcomes. Future STEM education programs should prioritize opportunities for PSTs to implement and reflect on their lesson plans during classroom practice [17,20,28]. Practical applications, combined with iterative feedback cycles, would enable the PSTs to refine their lesson designs and gain deeper insights into effective STEM teaching strategies. To achieve this, teacher educators could incorporate lesson study models through simulated teaching activities, such as microteaching sessions [64]. Additionally, a greater emphasis on formative assessment techniques, inclusivity, and open-ended exploration could enhance the quality and adaptability of STEM activities, which would allow the PSTs to better address the diverse needs of learners. By focusing on these key areas, teacher education programs can strengthen PSTs' knowledge, skills, and self-efficacy, thus ultimately preparing them to deliver engaging STEM learning experiences in their classrooms.

This study has several limitations. First, the study was limited to a small number of participants and focused on one specific STEM program within the Science Methods course. Therefore, the findings of this study may not be replicable in programs with different contexts and structures for supporting the PSTs' STEM teaching and learning. Second, the sample was exclusively composed of female PSTs, thus reflecting the demographic profile of the program at the time of the study. Though given prior research which suggested that gender may influence self-efficacy and confidence in STEM domains (e.g., [65]), the gender homogeneity of the sample may have shaped the results in specific ways. Future research should explore whether and how gender differences impact the development of STEM teaching efficacy beliefs. Other important limitations relate to the instrument used in this study. The STEBI-B was adapted for use in this study to measure the PSTs' beliefs about their efficacy in teaching STEM, and validity and reliability studies are required for this adaptation of the STEBI-B. Additionally, although a subset of PSTs had the opportunity to implement their STEM lesson plans during the teaching practice, this study did not investigate whether such a practical application directly influenced their confidence from those who did not teach their lessons. Exploring this variation could offer deeper insights into how authentic classroom experiences contribute to the development of STEM self-efficacy beliefs. Finally, this study did not follow the participants through the rest of their teaching program or when they started teaching. Consequently, there is no guarantee that the participants' improved STEM teaching efficacy beliefs will be sustained in practice. Future research should examine how cultural differences influence the development of self-efficacy in elementary PSTs [8]. Further longitudinal studies are needed to provide further insight into the translation of their endorsed self-efficacy beliefs into practice.

Author contributions

Teresa Ribeirinha: Conceptualization, Investigation, Methodology, Formal Analysis, Writing – original draft, Writing – review & editing; Marisa Correia: Supervision, Writing – original draft, Writing – review & editing.

Use of Generative-AI tools declaration

The authors declare that they employed artificial intelligence tools (DeepL Write® and Chat GPT®) to facilitate the process of writing in English.

Acknowledgments

This research was funded by national Funds through FCT—Portuguese Foundation for Science and Technology, I.P., under the scope of: Life Quality Research Centre (CIEQV) (UIDP/04748/2020).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethics declaration

The studies involving humans were approved by the Ethics Committee of the Research Unit of Santarém Polytechnic University. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants.

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