

ENHANCING STEM EDUCATION: EVALUATING EFFECTIVE TEACHING STRATEGIES IN PRE-SERVICE TEACHER EDUCATION

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Abstract

Scientists and Science Educators have promoted Science, Technology, Engineering, and Mathematics (STEM) education for at least two decades. Although STEM education is well-defined, there is no consensus on how to effectively integrate Science, Technology, Engineering, and Mathematics in primary and middle schools, where subjects are taught in silos. This two-year collaborative action research study was conducted by a Mathematics educator and a Science educator to investigate the effectiveness of STEM teaching strategies used in a teacher education program in Canada. The teaching strategies included Science and Math integration using lectures, workshops, and projects that utilized the Engineering Design Process and Coding. The instructors co-designed and implemented STEM teaching strategies and collected data from student teachers. Forty middle school pre-service teachers participated in the study. Data collection involved pre- and post-surveys, focus groups and student projects. The study's findings show that the STEM teaching strategies employed in the course significantly improved pre-service teachers' confidence and preparedness to use an integrated approach to STEM teaching. The study's findings add to the literature on transformative STEM teaching among pre-service teachers.

Keywords: *STEM teaching strategies, science and mathematics integration, teacher education, pre-service teachers, science education.*

1. Introduction

In a fast-growing and rapidly changing world, the fields of Science, Technology, Engineering, and Mathematics (STEM) have become critical to economic growth, technological advancement, and job competitiveness. Global challenges such as climate change, environmental sustainability, and public health require that students develop critical thinking and problem-solving skills. STEM education empowers learners to address the world's challenges and equips them with the skills they need. With the increased focus on cross-curricular implementation of STEM skills, the need for effective teacher education and instructional strategies is high. Although STEM education is clearly defined as the integration of Science, Technology, Engineering, and Mathematics (Bartels et al., 2019; Maiorca et al., 2020; Radloff & Guzey, 2016), there is no consensus on the most effective teaching methods to effectively integrate these subjects (Rinke et al., 2016). This lack of STEM strategies is mainly due to subjects being taught in silos in schools, making it challenging to provide authentic STEM instruction. This study intends to close this gap by investigating the effectiveness of STEM teaching strategies that explicitly integrate Science and Mathematics using the Engineering design process and Coding.

The study focused on breaking down silos in teacher education to provide pre-service teachers with authentic STEM learning experiences through collaborative co-planning and team teaching. The Science and Mathematics instructors engaged pre-service teachers in authentic STEM learning experiences that integrated Science and Mathematics through Coding and the Engineering Design Process. The collaboration benefited student teachers in this action research study because the Math instructor had a strong understanding of Coding and the Science instructor was well-versed in project-based learning using the Engineering design process. Expertise was also sought from Coding and Science Education experts, who were invited to provide workshops and mentoring for pre-service teachers. Both instructors taught students in the Middle School stream of a 5-year Bachelor of Education program at a medium-sized university. By collaborating and team-teaching on this project, the Mathematics and Science instructors aimed to leverage their teaching time through combined lectures, workshops, and integrated projects to provide pre-service teachers with an authentic STEM experience.

This study explored the effectiveness of instructional strategies for authentic STEM teaching for pre-service teachers by integrating Mathematics and Science using the Engineering design process and Coding. The Engineering design process, a multi-step approach, begins with extensive discussion and collaboration. Teams work to identify all possible solutions to a problem and then filter and adjust them into a working solution. Coding is an essential tool in modern technologies, including automation. The study intended to answer the following main question: What teaching strategies effectively enhance STEM education in pre-service teacher education? The following sub-question was also investigated: What are the pre-service teachers' perceptions of the STEM teaching strategies used?

1.1. Literature review

In recent years, there have been efforts to fund STEM initiatives to develop future leaders and workers capable of solving today's and tomorrow's complex challenges. In a study investigating career pathways among high school students, Nitzan-Tamar and Zehavit Kohen (2022) found that students who were more engaged in STEM subjects were more likely to pursue higher education or a STEM career.

Educators have attempted to make connections between subject areas since the early 1990s (Drake & Burns, 2004), encouraging students to draw on knowledge from multiple disciplines around a central theme to solve complex problems (Ryu et al., 2019). Judith Ramaley, the director of the Education and Human Division at the National Science Foundation, first introduced STEM in 2001 (Aguilera et al., 2021). STEM discourse first appeared in the USA curriculum in 2011 (NGSS, 2011). In Ontario, STEM education has reshaped the Science curriculum, making STEM the central strand that must be interconnected with all other Science strands. Despite these additions to the curriculum, there are no specific instructions for how STEM integration should be done. This lack of straightforward STEM education can evoke anxiety and insecurity among teachers, and, in the worst cases, teachers may reject the integration completely (Aguilera et al., 2021). Research has documented anxiety in Math and Science teaching among elementary and middle school pre-service teachers (Gonzalez-DeHass et al., 2027; Lorenzen, 2017; Morton & Dykeman, 2019), which negatively affects their students' learning outcomes. It is important to foster a positive attitude towards STEM subjects among elementary and middle school pre-service teachers, as they serve as role models and their practice shapes their students' future education (Uddin, 2022).

Developing an authentic understanding of STEM teaching among pre-service teachers ensures that their future learners are prepared to contribute positively to economic growth and address global challenges. Project-based learning is a powerful method for engaging and appealing to students (Terada, 2018). Vital pre-service teacher resources, such as mentoring, can yield significant gains in their ability and confidence (Alemdar et al., 2022). STEM education is more than just being knowledgeable about the subjects; it involves an insightful look into the applications of Science, Technology, Engineering, and Mathematics in real life. Through STEM education, learners develop a deep understanding of problem-solving, application, and practical skills in information analysis, error elimination, and critical thinking for proper action (Norris, 2022).

The entire push for excellent STEM education and equitable opportunity for all students falls to the teacher and their delivery. Research has shown a positive correlation between teacher competence in a particular subject area and their confidence to teach the subject (Dierking & Fox, 2013). Examples of STEM teacher training programs include the Noyce Scholarship Program, which was created to bring teachers into STEM fields in high-need schools (Alemdar et al., 2022). Participants with access to solid support resources, particularly mentorships, were more likely to continue, better prepared for the content, and more likely to retain their role in teaching STEM subjects (Alemdar et al., 2022).

2. Research design

This qualitative action research study investigated the effectiveness of STEM instructional strategies used in preparing pre-service teachers in the middle school division. A collaborative action research (CAR) framework was used to leverage and integrate knowledge and expertise in Science and Mathematics while reflecting on and learning from practice (McNiff & Whitehead, 2002) to better understand the practice's effectiveness. A collaborative action research (CAR) framework was used to leverage and integrate knowledge and expertise in Science, Technology, Engineering and Mathematics while reflecting and learning from practice.

2.1. Study participants and data collection

A total of 40 pre-service teachers participated in the study over two years. These students were in their final year of the Bachelor of Education program. The study participants agreed to participate in online and in-person STEM workshops planned during the school year, in addition to the regular STEM workshops offered to all students. Data were collected through pre- and post-surveys at the beginning and end of each

academic year. The surveys sought students' knowledge and experiences with STEM education before and after taking the course and participating in extra STEM activities. Focus groups were held at the end of the school year to provide feedback, perceptions, and experiences on the STEM teaching strategies used in the course. Data from the pre- and post-surveys and focus groups were coded, and thematic analysis was conducted to identify emerging themes.

2.2. Teaching strategies used

In addition to the regular Mathematics and Science coursework, the instructors organized coding training sessions and invited a STEM coordinator from the local school board to offer additional in-class coding workshops using Scratch, Microbits, Ozobots and Spheros. Engineering design workshops were organized outside class time for the study participants. The culminating evaluation project for the collaborative study was an integrated STEM project in which students applied their STEM knowledge by using the Engineering design process to design and build a prototype or write code to demonstrate a scientific concept.

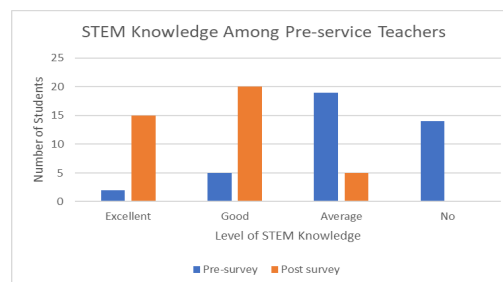
3. Results and discussion

A total of 40 pre- and post-surveys were collected. Additionally, 40 detailed responses were collected from the study participants. The results showed that STEM strategies that integrated the four STEM subjects through coding and the engineering design process were effective in improving STEM learning and understanding among pre-service teachers. Overall, the data analysis showed the following themes: a) improvement in pre-service teacher knowledge and understanding of STEM education and teaching strategies, such as Coding and the Engineering Design Process; b) improved confidence in future STEM teaching; and improvement in the quality of culminating projects completed by study participants who demonstrated creativity, critical thinking, and enhanced technological problem-solving skills.

3.1. Effectiveness of teaching strategies to enhance STEM knowledge

A comparison of the pre- and post-survey data is shown in Figure 1 below. The graph shows a significant improvement in students' ratings of their understanding of STEM.

Figure 1. Level of STEM knowledge among pre-service teachers.



Pre-survey data showed that a significant number of pre-service teachers either had no idea (35%) or were unsure of their understanding of STEM education, 48% rated their understanding as average, 13% as good, and 4% as excellent. Post-survey data showed a drastic improvement, with 38% rating their STEM knowledge as excellent, 50% as good, and 12% as average. The participants attributed their improved understanding of STEM to the integration project, which helped them use Coding and the Engineering design process to demonstrate how Science and Mathematics are used in everyday life using technological and engineering processes. This fact was further highlighted in the following quotation from the focus group:

"Working on the STEM integration project opened my eyes regarding the power of STEM and how it can be leveraged to prompt enthusiasm for learning. Having created a STEM roller coaster project allowed my group members and me to see the benefits of synthesizing math and science content. I think that by synthesizing these subjects, students can attain a far more holistic learning experience, since math and science can be fully cross-curricular and the prototypes students create provide real-world applications that extend beyond the classroom."

The pre-service teachers acknowledged that understanding STEM teaching strategies helped them realize that STEM was less daunting than they had initially thought. Intentional integration of math and science using the engineering design process helped students improve the quality of their projects by

consistently reflecting on how the chosen math strand could be used to create their product, as stated by one participant in the quotation below:

“The STEM project improved my understanding of applying these concepts to real-life through the backwards design approach we chose to take. I think knowing our end goal made it even more interesting to plan how to achieve it. As I leave this experience, I feel enthralled to provide students with multiple opportunities to demonstrate their STEM skills.”

The quotation below from one of the participants emphasizes the fact that the STEM strategies used in the course were effective in demonstrating how the four STEM subjects can be integrated seamlessly through the engineering design process and/or coding:

“STEM instruction differs from other types of instruction in a couple of ways. STEM focuses on integrating 4 subject areas into a single, holistic lesson. All 4 subjects correlate/fit seamlessly with each other. It may seem complex, but creating a STEM lesson is a pretty straightforward puzzle.”

Providing additional workshops and practice outside regular class was necessary to ensure that pre-service teachers had enough time to develop a solid understanding of STEM teaching strategies. The importance of additional learning experiences and practice was highlighted in feedback from study participants, who emphasized the need to provide more practice, such as increasing the number of STEM projects students complete for the course.

3.2. Pre-service teacher perceptions about STEM teaching experiences

Findings from the focus groups showed that, in addition to understanding the STEM teaching strategies used in the courses and workshops, the pre-service teachers developed confidence in using authentic STEM teaching strategies. Table 1 below presents an analysis of student sentiments from the focus groups, showing that the majority of study participants reported increased confidence in their ability to teach STEM using strategies they learned from the course.

Table 1. Pre-service teacher perceptions about their STEM teaching ability.

Response Type	Number of responses	% (total number 40)
Confident and prepared	15	38%
Somewhat prepared	17	43%
Confident & growth	8	19%

During focus groups, study participants expressed confidence in STEM teaching and were excited to implement STEM projects in future classrooms. One participant noted that *“Now that I have a better breakdown/understanding of the Engineering Design Process, I will certainly use it in my classroom for STEM-related activities.”* Similarly, students reported increased confidence after attending the extra coding workshop offered to study participants. This sentiment is highlighted in the following quotation: *“I am going to feel more confident introducing my class to coding assignments. Prior to this workshop, I was only familiar with Scratch, but now I feel like I have a handful of new resources and programs to work with”*. Additionally, the pre-service teachers were able to make connections between STEM and the arts, demonstrating that working on the project helped them realize possibilities for extending beyond Science and Mathematics in future teaching. This highlights the effectiveness of the collaborative action research approach in pre-service STEM teaching.

In addition to being confident in STEM teaching, a few participants (8%) noted partial gaps in their knowledge due to a lack of practice in real classrooms. These students identified partial gaps in their understanding of coding that they felt would affect their future STEM teaching. Despite the gaps, the participants demonstrated a propensity for lifelong learning to properly implement STEM in the classroom. Overall, the findings show that providing more time for pre-service teachers to practice new teaching strategies is beneficial.

4. Conclusion

The pre-service teachers who participated in the study had an improved understanding of STEM education and STEM teaching strategies and were confident in their ability to teach STEM. The Findings highlight the importance of collaboration and the power of mentoring pre-service teachers through providing support, resources and extra time to practice, in addition to regular lectures. The challenge faced by most teacher educators is having enough time to help pre-service teachers practice new teaching strategies. By collaborating on STEM instruction, this project enabled us to leverage our skills and time to provide rich STEM learning experiences for pre-service teachers. In addition, collaborating with other

STEM experts in our community provided student teachers with real-world STEM practice, deepening their understanding of STEM teaching. The engineering design process appears to be a strong anchor for helping pre-service teachers organize STEM instruction. Coding remained a concern for some, as it was the first time most students were learning it, and they wanted a deeper understanding beyond just executing code. Modelling a collaborative approach to STEM teaching was a powerful way to demonstrate possibilities for authentic integration of the four subjects.

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