

STEM teachers are the future educators: The effectiveness of the STEM approach in preparing cycle-one teachers and their perceptions towards the approach

Ali Khaled Bawaneh^{1*} , Osamah Mohammad Ameen Aldalalah² , Subreen M. Al-Salman¹ ,
Enaz Mahmoud¹ 

¹ Department of Mathematics, Science and ICT, Muhammed Jaber Al-Ansari College for Teachers, University of Bahrain, Sakhir, BAHRAIN

² Department of Curriculum and Teaching, Faculty of Educational Sciences, Yarmouk University, Irbid, JORDAN

Received 22 September 2025 ▪ Accepted 16 February 2026

Abstract

The purpose of this quasi-experimental study was to investigate how well 133 student teachers in a science course learned and perceived the STEM technique in comparison to the conventional approaches. There were 76 pupils in the experimental group and 57 in the control group. There were no discernible variations depending on gender, but data analysis (using ANCOVA) revealed a statistically significant difference favoring the STEM approach over the conventional one. Additionally, the great majority of students (97%) stated that the STEM approach improved their leadership and higher-order thinking abilities as well as their drive and enjoyment, indicating its beneficial transforming effect on their perceptions toward science. The study suggests incorporating the STEM methodology into teacher training programs, offering the required professional development, reorganizing curricula, and preparing schools to facilitate its successful implementation in light of these findings.

Keywords: STEM education, cycle one teachers, future educators, teachers' perceptions, STEM effectiveness

INTRODUCTION

Adopting contemporary teaching methods that align with the demands of the 21st century has become crucial amidst rapid technological advancements and the digital revolution (Almutairi, 2023; Bawaneh et al., 2025). The science, technology, engineering, and mathematics (STEM) methodology is one widely accepted strategy in this context (Bawaneh & Malkawi, 2023; English, 2016; Kazu & Alchin, 2021). Furthermore, today's learners differ from those of the past in that they are characterized by active participation and frequent questioning. STEM education supports the creation of educational pathways and opportunities that provide students with high-quality learning and professional experiences in these fields, thereby preparing them for better future careers (Adebayo, 2022). It also enables students to develop the skills needed to engage with STEM-related topics, issues, and real-world challenges,

making them capable of critical thinking, creativity, and effective problem solving in the 21st century (Adebayo, 2022; Akcan et al., 2023; Ayverdi & Öz Aydın, 2020; English, 2016). In addition, STEM education promotes the design and implementation of learning materials that foster creativity, analytical thinking, and exploratory skills. This is achieved through integrated instructional activities based on effective teaching strategies such as inquiry-based learning, engineering and technological design, problem-based learning, design thinking, active learning, project-based learning, and collaborative learning across all levels of education (Al-Deghaim, 2017; Al-Qadi, 2019; Almutairi, 2023; Bawaneh & Malkawi, 2023; Hussain, 2021; Wahono et al., 2020;).

STEM education is widely understood as an integrated instructional approach that connects science, technology, engineering, and mathematics to promote meaningful learning through interdisciplinary problem solving (Al-Qadi, 2019; English, 2016; Sanders, 2009).

Contribution to the literature

- This study aimed to reveal the effectiveness of the STEM approach in preparing cycle one teachers, especially since these student teachers will be teaching all the courses to their students.
- The results confirmed the effectiveness of this approach in preparing future teachers.
- The qualitative data emphasized the importance of this approach in activating the role of students as the core of the teaching and learning process, and as participants in the production and application of knowledge.

This requires enabling teachers and learners to understand engineering and scientific practices, the interconnected concepts, and the fundamental ideas of STEM (Ayverdi & Öz Aydın, 2020). It also requires preparing learning environments in a real-world context so that participants in workshops and educational projects can engage with scientific topics in a meaningful and applied manner rather than through isolated theoretical instruction (English, 2016; Wahono et al., 2020). The STEAM extension is acknowledged in the literature; however, the present review focuses specifically on empirical findings related to STEM-based instruction in teacher education contexts (Adebayo, 2022; Ayverdi & Öz Aydın, 2020; Kazu & Alçin, 2021).

Many researchers (Adebayo, 2022; Almutairi, 2023; Al-Qadi, 2019; English, 2016; Hussain, 2021; Radwan, 2019; Salha, 2022; Wahono et al., 2020) emphasize the above definitions and point out that educational institutions that adopt the STEM approach aim to enhance students' abilities to connect theoretical knowledge with technological applications to serve society. This is achieved by integrating four main fields, as follows:

- **Science:** This field focuses on acquiring scientific knowledge across disciplines so that it can be used to understand the natural world.
- **Technology:** This field focuses on employing technological applications and modern techniques in the educational process, to develop the skills needed to analyze the impact of technology on the individual and the wider world.
- **Engineering:** This refers to the ability to be creative and innovative in engineering designs by applying scientific and mathematical principles for practical problem solving and real-world applications.
- **Mathematics:** This refers to the ability to represent ideas symbolically and analyze them, as well as formulating and solving mathematical problems and applying them in real-world contexts.

Some studies (Bawaneh et al., 2025; Chine & Larwin, 2022; Kazu & Alçin, 2021; Salha, 2022) indicate that teachers in STEM schools play a facilitating role in students' learning. They guide students, develop the

learning environment in line with the curriculum, design learning questions, formulate problems, and support student achievement by providing direct and continuous feedback to ensure that students' projects and deep understanding remain focused on the expected and stated goals from the beginning. Teachers should be careful not to provide students with answers but instead leave space for students to search for solutions to the problems they face in the educational process. The STEM school teacher is distinguished by strong distinctive mental abilities, which enable them to manage the educational process in a new and innovative manner. They must be able to use modern technologies in the teaching and learning process and explore topics related to their specialization through information networks. One of their most important roles is to provide the student with a common direction or shared focus. This is achieved by informing students of what they are expected to achieve or accomplish in the project and helping them connect real-world experiences to what they learn. The teacher also supervises students' projects and allows them to collaborate with the wider community and other educators (Almutairi, 2023; Bawaneh et al., 2020; Parminder, 2019; Wahono et al., 2020).

Research Problem and Questions

Among the modern approaches that support authentic applications of science learning and assessment and enhance higher-order thinking skills, which contribute to solving educational, social, economic, and other problems, is the STEM approach. Solving real-world problems requires students to know how to connect different sciences to create innovations that bridge gaps in sustainable development and contribute to meeting labor market needs, along with other relevant skills, knowledge, and attitudes (Bawaneh & Malkawi, 2023; Bureau, 2015). Based on the foundations of constructivist theory, it has been found that the STEM approach enhances creative thinking. The constructivist pillars that resonate with STEM education (Bruning et al., 2004; English, 2016; Salha, 2022; Wahono et al., 2020) emphasize that learning is an open, constructive process and that motivations and beliefs are integral parts of cognition. Moreover, learning stems from knowledge, strategies, and experiences linked to relevant contexts. Accordingly, when teachers adopt a

STEM approach in their teaching, assessment, and test preparation, this approach can enhance higher-order thinking skills, particularly creativity and innovation, among students.

Based on recommendations inspired by the results of numerous studies (Ayverdi & Öz Aydın, 2020; Bawaneh & Malkawi, 2023; Brini & Hill, 2013; English, 2016; Kazu & Alçin, 2021; Wahono et al., 2020) aimed at developing future visions in light of the rapid changes in learning, teaching, and instructional systems, these studies emphasize on the importance of developing the educational system and transforming the educational philosophy based on providing STEM education to everyone and implementing it in all schools. To achieve this, countries must commit to providing financial support for the implementation of the STEM learning systems in all educational institutions and upgrading schools by incorporating modern technological media and techniques in the educational process. More importantly, Hattie and Zierer (2025) in their well-known study *Visible Learning*, emphasize the importance of continuous training and professional development for teachers, as they are the most influential force in the educational system. Providing training and professional development for teachers in using this educational approach is of paramount importance, in addition to developing curricula that align with the principles and core elements of the STEM approach and establishing methods and indicators to measure progress and identify strengths and weaknesses. In this context the current study aims to investigate the effectiveness of the STEM approach on the performance of student teachers who, after graduating from university, are expected to teach first-cycle students (first, second, and third grades) in primary schools. The current study seeks to answer the following questions:

1. **Question 1:** What is the effectiveness of using the STEM approach on student teachers' performance in the science course compared to the conventional method? Does this performance differ by student gender?
2. **Question 2:** What are the students' perceptions of the STEM approach in terms of its strengths? Is it appropriate for supporting student learning?

Significance of the Study

The importance of the study lies in its application of the STEM approach to preparing future teachers for first-cycle students. It is hoped that the results will provide recommendations for teachers in the educational field, faculty members in educational colleges, decision-makers, educational policymakers, and the academic community concerned with applied teaching that enhances higher-order thinking skills. This will help develop a clear roadmap for preparing creative teachers

who **foster** a generation of creative thinkers who actively contribute to the production and construction of knowledge.

Operational Definitions

STEM approach

A teaching approach that combines science, technology, engineering, and mathematics in the science (1) course for undergraduate students specializing in first-cycle teacher's education. This approach addresses course content in an integrated manner from various perspectives. Scientific inquiry, technological and engineering design, and problem-based learning are employed using design thinking, with collaborative learning **integrated** throughout all stages.

Study limitations

The study limitations can be summarized as follows:

- It is limited to a specific course, science (1), taught to second-year undergraduate students in the teacher education program, first-cycle.
- Students enrolled in the science (1) course in the first semester of the 2024-2025 academic year.
- The degree of validity and reliability of the data collection tools.
- The degree of fidelity in implementing the proposed teaching method according to the agreed-upon plan.

According to Bureau (2015), the STEM approach is a model of teaching and learning that emphasizes research, critical thinking, problem-solving, and project-based learning. Students use technology to apply the knowledge they have gained in science, mathematics, and engineering. The STEM methodology, which stands for science, technology, engineering, and mathematics, requires the integration of teaching, learning, and assessment. To achieve this, it is essential to create a learning environment within a meaningful real-world context that goes beyond theoretical concepts often taught in classrooms, enabling students to acquire comprehensive and interconnected knowledge of relevant subjects. According to Bawaneh and Malkawi (2023), the STEM approach strongly emphasizes integrated conceptual experiences, which include scientific inquiry, problem-solving, and extensive practical application. Furthermore, it stresses authentic, multifaceted, performance-based assessment, focusing on the development of metacognitive skills, along with critical and creative thinking abilities.

The STEM approach demonstrates the relationship between discipline content, curricula, problem-based learning, research, inquiry, and the practice of lifelong learning habits. Several studies (Brini & Hill, 2013; Cheng et al., 2024; English, 2016; Wahono et al., 2020)

indicate that learning according to the STEM approach has certain conditions, the most important of which is that it is continuous, lifelong learning, as it is project-based, i.e., integrating knowledge with work. This is achieved through activating teamwork and participation and employing specific disciplines (science, technology, engineering, and mathematics), focusing on facts, concepts, theories, and principles rather than isolated skills.

Employing the STEM approach in education requires providing and preparing a learning environment that encourages learners to enjoy and engage in STEM-integrative workshops, enabling them to develop their knowledge and skills in a way that allows them to understand and comprehend science in a simple, accessible, and enjoyable way, through both in-class and extracurricular learning.

Researchers (Al-Qadi, 2019; Ayverdi & Öz Aydın, 2020; Bruning et al., 2004) confirm that STEM education is rooted in constructivism theory and the findings of three decades of cognitive science. According to Bruning et al. (2004), the constructivist principles that resonate with STEM education are:

- Learning is a constructive and open process.
- Motivation and beliefs are integral to cognition.
- Social interaction is essential for cognitive development.
- Learning stems from contextual knowledge, strategies, and experiences.

Based on the above, STEM-based curricula, activities, and teaching strategies should be designed in a systematic and innovative way. This approach helps students grasp the fundamental concepts of various sciences in a clear, interactive, and integrated manner, connecting them to their surrounding environment and integrating them with their prior knowledge and skills. This enables learners to develop essential skills for their daily lives. Proponents of STEM education, including Rogovaya et al. (2019), Singh et al. (2021), Dagger (2013), and Al-Qadi (2019), argue that this approach improves educational outcomes by successfully integrating the four disciplines. STEM education has garnered the attention of international organizations seeking to enhance their human resources in specialized sectors to support innovation and competitiveness, given the significant overlap in modern inventions and innovations across different disciplines. The National Governors Association is one such organization, aims to improve teacher competency in these areas and increase student enrollment in graduate studies in related subjects (Mahmoud & Bawaneh, 2025; Thomasian, 2011).

Several researchers (Ayverdi & Öz Aydın, 2020; Bawaneh & Alnamshan, 2023; Singh et al., 2021; Stephanie, 2008) have discussed the requirements for implementing STEM education, identifying three key

dimensions for transitioning from a traditional curriculum to an integrated, experiential approach. These dimensions can be summarized as follows:

The first dimension: By bringing what students learn in the classroom into line with their everyday lives, this vision seeks to revolutionize the way science and mathematics are taught. There are many difficulties and concerns about how science is taught in schools. Science instruction frequently fails to promote students' understanding of scientific ideas, hinders inquiry and discovery, and lacks experimentation and practical application. Additionally, students feel bored and frustrated in science and math classes, which makes them dislike these topics, especially in secondary school. This can be linked to the overload of information and instructional strategies in which the instructor merely imparts knowledge without offering opportunities for inquiry, discussion, investigation, and independent thought.

Instead, the emphasis is on memorization and recitation of previously answered questions. Reluctance to carry out experiments and scientific research results from this loss of interest, enthusiasm, and the urge to investigate. Additionally, science education fails to relate to students' everyday lives and social environment; science is taught in isolation from other fields rather than being integrated, and interdisciplinary concepts are lacking. However, research shows that integrated experimental curricula emphasize investigation and exploration abilities in order to address the objectives of science and math education (Bawaneh & Alnamshan, 2023).

It focuses on meaning rather than rote knowledge, emphasizes research and discovery rather than mere achievement, and cultivates a culture of cooperation rather than competition, encouraging interdependence rather than independence among students. It also relies on analysis and reasoning, formulating hypotheses and conducting scientific experiments, and then making judgments based on evidence. These practices foster both trust in others and self-confidence.

The second dimension: This domain requires a transformation in the way science and mathematics are taught in schools, to develop students' scientific knowledge, skills, and behaviors and enable them to practice science, research, investigation, and problem-solving in creative ways. This requires designing science content according to an integrated STEM methodology, including integrated experiments in lesson plans, using problem-based inquiry, and creatively utilizing modern technologies and artificial intelligence, with a focus on practical application and scientific processes such as guided and open inquiry and participation in research, in addition to applying continuous performance-based assessment.

The third dimension: This dimension revolves around changing educational objectives to ensure that all individuals achieve a comprehensive understanding of science, mathematics, and their applications.

This is accomplished by using a multidisciplinary and integrated approach rather than teaching STEM in isolation. This method encourages design, creativity, and innovation while acknowledging the close connection between STEM disciplines. This necessitates creating an environment in the classroom that motivates students to take part in and enjoy learning experiences that incorporate these sciences, allowing them to advance their knowledge and abilities and comprehend science in a clear, accessible, and engaging manner. This perspective applies to learners at all educational levels and across both formal and non-formal learning contexts.

Many studies (Al-Qadi, 2019; Kazu & Alçin, 2021; Parno et al., 2021; Rogovaya et al., 2019) point to the strengths of the STEM approach, the most important of which are:

- The STEM approach is considered an effective model for the educational process, as it supports the development of skills to help students meet the challenges of the 21st century.
- The STEM approach is based on connecting the educational process to reality, engaging the community, and collaborating to solve its problems.
- The teacher's role in this approach is to facilitate and guide the educational process, helping students solve problems. Teachers also help formulate problems and clarify learning objectives.
- This method centers the entire educational process around the student and their development, making the student the heart of the learning process (Al-Ghamdi, 2018; Allan, 2019).

As with any teaching approach or practice, there are bound to be some challenges and limitations. Some studies (Bawaneh & Malkawi, 2023; Rogovaya et al., 2019) point to limitations in the STEM approach, the most important of which are:

- The use of modern technological tools poses a major challenge in some countries due to limited technological infrastructure.
- Schools in many countries lack teachers skilled in employing technology and artificial intelligence in education, as well as in developing 21st century skills.
- additional research is needed into the concept of this approach and how to apply it to achieve success and increase the effectiveness of the educational process (Al-Ghamdi, 2018; Allan, 2019).

Analytical thinking and the STEM curriculum are positively associated, according to an assessment of the findings of multiple studies on the programs' practical implementation. According to a study by Chonkaew et al. (2016), problem-solving-based STEM learning effectively improved students' analytical thinking abilities and attitudes toward learning science. This enabled them to understand key concepts and use their expertise from many disciplines to solve problems and create original solutions. Nearly 80% of students scored high on critical thinking skills, surpassing the set criterion of 70%, according to the study.

In a similar vein, Singh et al. (2021) designed, produced, and tested two engineering products a submersible and a small hydraulic elevator - using a quasi-experimental research methodology. Their goal was to investigate how STEM (science, technology, engineering, and mathematics)-based teaching methods could improve students' capacity for higher-order thinking. The findings of the study demonstrated that both models were effective in fostering students' critical thinking skills.

Al-Malki's (2018) study used the Intel ISEF model criteria with fifth-grade students in Jeddah to assess the efficacy of teaching science using the STEM methodology. The mean (M) scores of the students in the experimental and control groups did not differ statistically significantly, according to the data. The mean scores of science practices in the pre- and post-tests, however, differed statistically significantly in Abu Musa's (2019) study, which employed the same quasi-experimental methodology as Al-Malki's (2018).

A study by Rahayu et al. (2018) that sought to determine the issues related to applying the STEM methodology in secondary schools reported similar findings. The study found that the STEM-based curriculum is successful and enhances teacher effectiveness. In a similar vein, Chin and Larwin (2022) conducted seven-year longitudinal study in Ohio, USA, to confirm the impact of the STEM approach on student achievement in comparison to the conventional method.

The results showed that STEM-oriented education had a significant positive impact on combined mathematics and science achievement, with participants scoring 31.8 points above the average, and science-only participants scoring 38.2 points above the average, compared to participants in the control group, respectively. This was confirmed by Muhammad and Makhdoom's (2022) study conducted in Pakistan. The study included 200 randomly selected teachers, and qualitative data were collected through a questionnaire specifically designed for that study. The results indicated a strong need for teachers to integrate STEM activities into the classroom environment. The study found that education stakeholders should facilitate teachers' use of STEM-integrated training with the

necessary resources and support teachers by providing professional development opportunities. The study also suggested allocating funds to develop and enhance the STEM-integrated teaching and learning process. Most educators agreed that integration requires a multidisciplinary approach and remains challenging.

Cheng et al.'s (2024) study aimed to design a STEM curriculum with an emphasis on explicit and continuous reflection on students' thinking about scientific and engineering knowledge. The primary goal was to promote knowledge integration in their engineering designs and enhance their attitudes toward STEM. The study involved fifty students who were guided to discuss and reflect on relevant scientific and engineering knowledge and to apply mathematics to collect and analyze data while designing their technological products. The research tools included an assessment of the progress in knowledge integration in students' engineering designs. The results indicated that students' performance in scientific and engineering knowledge gradually improved. Their attitudes toward STEM and the learning environment were also enhanced compared to the regular curriculum.

One important study in this field is the meta-analysis carried out by Kazu and Yalçın (2021). By analyzing the findings of 64 studies published between 2014 and 2021 in major databases like ERIC, Web of Science, EBSCOhost, Google Scholar, SCOPUS, ProQuest, and the CHE Thesis Center. This study sought to ascertain the overall effect of the STEM approach on students' academic achievement. The findings demonstrated that the STEM method had a statistically significant effect on students' academic performance, with science disciplines showing the biggest benefit compared with mathematics, engineering, and technology.

According to Margot and Kettler's (2019) study, the STEM approach has significant implementation issues even when teachers recognize its benefits. In order to comprehend the perspectives of kindergarten through twelfth-grade instructors, the researchers examined the empirical literature published between 2000 and 2016. The findings demonstrated that teachers identified a variety of difficulties, including instructional, methodological, and structural factors, as well as issues with students, tests, and the lack of support they received. Teachers believed that peer collaboration, a strong curriculum, district or school-system support, prior experience, and successful professional development would all help them in their efforts to introduce STEM education.

A study by Akcan et al. (2023) focused on teachers' perceptions of the efficacy of the STEM curriculum and its role in developing the labor market and related socio-economic outcomes. The study used descriptive and inductive approaches to analyze qualitative data. The findings showed that STEM education expanded

Table 1. Study sample according to its variables (gender and teaching methods)

Independent variables		N
Students' gender	Male	52
	Female	81
Teaching method	STEM	76
	Conventional	57
Total		133

employment prospects, promoted entrepreneurship, and offered new professional sectors. They also mentioned how STEM education contributed to lowering societal costs. In addition, this curriculum minimized brain drain, decreased social difficulties, and increased stakeholder satisfaction. On the other hand, they noted that STEM education can lead to technological unemployment. Descriptive analyses showed that STEM education had a positive impact on employment, reduced social costs, and helped address labor shortages.

METHODOLOGY

To achieve the study objectives, the researchers adopted a quasi-experimental design, in addition to collecting qualitative data from the student sample. All students enrolled in a specific course designed according to the STEM approach were targeted, compared to students in other sections that were taught using conventional methods. It should be noted that random selection was carried out at the section level, with no opportunity to reassign students between sections representing the experimental or control groups in the study, which renders the research design quasi-experimental. Ms, standard deviations (SDs), percentages, and inferential analyses were conducted using ANCOVA.

Study Population and Sample

The study population consisted of all second-year student teachers for first cycle in the department of primary education at a university in the Arabian Gulf region for the 2024/2025 academic year. These students are registered in the science (1) course. It is worth noting that these students' study in a college of education and are being prepared to be teachers for first-cycle students (first grade, second grade, and third grade). The sample included students from two groups; the experimental group used the STEM approach, while the control group used the conventional approach. It is worth noting that the researchers controlled various variables such as the number of teachers and the cognitive content presented in all sections, regardless of the teaching approach. The study sample included 133 male and female students: 76 students studied according to the STEM approach, and 57 students studied the same content using the conventional method, as shown in **Table 1**.

It should be noted that all students live in largely similar cultural, economic, and social contexts. They are also close in age (20-21 years old), speak Arabic as their first language, and are fluent in English as a second language. All students took the course as a requirement for their undergraduate studies as prospective first cycle teachers. Data were collected over a full semester of four months. Alternative assessment included individual reflections on typical STEM lessons and a midterm exam with two types of questions (objective and open-ended) that was designed to achieve learning outcomes according to test specification table. Each student was also required to design microteaching learning activity compatible with the STEM approach and present it to their classmates for 15 minutes. They then reflected on their teaching performance. At the end of the semester, a set of open-ended reflective questions was posed, including the strengths, weaknesses, and areas for improvement of the course, as well as students' level of satisfaction with it.

Instrument validity

To ensure the validity of the study instruments, the instruments included an individual reflection task based on a STEM-model lesson delivered by the instructors, a midterm achievement test, an individual microteaching design task aligned with STEM focal points, and a microteaching self-reflection tool. Furthermore, additional instruments were used to collect qualitative data on strengths, areas for improvement, and satisfaction with the teaching approach. All instruments were presented to a panel of eight experts who held doctoral or master's degrees in science, math curricula and teaching methods, and educational technology. The instruments were revised based on their comments and recommendations, to ensure alignment with the STEM approach and improve content validity.

To minimize this bias, students were randomly assigned to groups (sections) rather than individuals, and the basic characteristics of the sections were carefully matched. This randomization method also enhances internal validity, especially considering the thorough preparation of daily lesson plans and the professional training of instructors. It's worth noting that all students in the study were subject to the same selection criteria for college admission from the outset, and their ages were similar (around 20 years old).

Instrument reliability

To calculate the reliability of the study instrument - the midterm achievement test - the researcher calculated Cronbach's alpha coefficient, and the coefficient was 0.862. This value is considered appropriate for collecting data in the humanities and social sciences (Al-Kellani & Al-Shraifeen, 2011; Obiedat et al., 2016).

STEM Teaching Method

Understanding the connections between the many sciences is crucial to achieving the integration of science, technology, engineering, and mathematics, which is the foundation of the STEM approach. The STEM approach also relies on several strategies, including inquiry-based learning, engineering and technological design, problem-solving, design thinking, project-based learning, and brainstorming, which includes both divergent and convergent thinking. All these strategies involve questioning and developing students' ability to identify cause and effect, observe, and determine the characteristics of objects. This is precisely what was adopted in designing the science curriculum implemented with the students in the current study's experimental group. The fundamental elements of the STEM approach—scientific inquiry, engineering and technological design, problem-based learning, and teamwork—were incorporated into the course design by the researchers. The activities included in the textbooks for the science curriculum in the first cycle, approved by the Ministry of Education, were covered, considering the general competencies for the first cycle—for the science curriculum—and the main and sub-competencies for each grade (1, 2, and 3). The following steps were taken in the design of the four-month course:

Stage one

Designing the first part of the knowledge, skills, and attitudes that cover the learning outcomes targeted by the scientific inquiry strategy through collaborative group work. In line with the main goals of scientific research and teamwork, several dive activities were developed, including shadow formation, the connection between permeability and absorption of different soil types, and the relationship between time, distance, and slope angle. These activities include:

Observing and asking questions about the natural environment. Planning and conducting simple investigations. Using simple equipment and tools to gather data and extend the senses. Using grade-level-appropriate mathematics to construct reasonable explanations from data. Reviewing and questioning the observations and explanations of others. Using modelling technique, the teacher guides and carries out the student-led tasks. They continually remind the students, "Imagine that you are the teacher and will later implement these activities in your own classroom." They use tools and materials to conduct the inquiry experiment in groups, apply the focal points of scientific inquiry, and create all the materials and requirements for presenting the scientific content. Students collect and analyze data, link it to mathematics, and reach conclusions specific to each group based on the data they collect and their interpretations of these conclusions (Mahmoud & Bawaneh, 2025).

After that, the instructor starts a lively discussion in which all groups express their ideas and interpretations and provide helpful feedback from one another. This part represents an important opportunity for students to learn from one another, enhance self-confidence, and appreciate the value of science and its relationship to the natural world.

Stage two

Applying knowledge and skills covering the targeted learning outcomes by enhancing students' skills in technological and engineering design using problem-based learning and design thinking, as well as encouraging students to work collaboratively in a group setting. Scenarios were developed based on situations inspired by first-cycle textbooks, representing general and sub-competence. Each student group was required to choose one of these scenarios, with the following being the most representative:

1. Design and build a small boat out of recycled materials that can float in water for a specific period. identify the purposes of the technology you have developed and outline the potential effects on people.
2. Design and build (with teacher support) a working worm composting bin or an ant farm (whichever is most appropriate for the classroom) that can be used to observe behavior of the worms or ants. Identify the goals of your designed technology and specify how it can impact humans.
3. Design and construct a device to move a matchbox car from one position to another without touching it. Test and evaluate your design. Identify the goals of your designed technology and specify how it can impact humans.
4. Design and construct a pond, water garden, or wetland environment in a terrarium. Evaluate different soil types to ensure that the chosen soil can hold water and support plant life. Present an explanation of the process and the findings to the class. Identify the goal(s) of your designed technology and specify how it can impact humans.
5. Research, design, and construct a model of a simple energy collection system for a specific location in Bahrain. Provide a selection of everyday materials for the model, such as PVC piping and transparent/aluminum foil, to make a windmill or water wheel to allow student-led investigation and design. Identify the goals of your designed technology and specify how it can impact humans.
6. Design and construct an instrument that can measure wind speed and wind direction. Evaluate

the properties of the chosen materials and the design as part of the testing and decision-making process. Demonstrate the final product to the class. Identify the goal of your designed technology and specify how it can impact humans.

Here begins the journey to solve the problem by building a technological and engineering design according to the following focal points:

- Identifying problems and potential technological/engineering solutions.
- Implementing the design process and the role of troubleshooting.
- Identifying goals of physical, informational, and bio-related technologies.
- Identifying how physical technologies impact humans.

This is done by the course instructor using a modelling approach, reminding the students once again, "Imagine that you are the teacher and will later implement these activities in your own classroom." The instructor invites students to brainstorm at the group level using divergent thinking and identify the problems associated with their chosen scenario. The instructor reminds them not to place any restrictions or limitations on ideas and encourages them to think outside the box and come up with creative and unconventional ideas. During this process, the instructor visits the groups, providing constructive feedback when necessary and ensuring that students are on the right track and applying the required procedures at each stage. The instructor then asks the students to compile their ideas and develop a set of criteria to filter them accordingly through convergent thinking, arriving at a clear definition and formulation of the problem. At this stage, groups may initially identify more than one problem related to the chosen situation. The instructor then directs the groups to select a single problem that represents the chosen situation and work on finding a solution.

Here, the divergent thinking phase begins again—through brainstorming—with each group working to come up with the maximum number of proposed solutions to the problem. At this stage, there are no restrictions or limitations, such as cost, tools, implementation capacity, etc. What matters most are creative, innovative, and unconventional solutions. The teacher then guides students toward convergent thinking by establishing a set of criteria to filter solutions and select the best one to complete the next stages. After selecting the optimal solution from the group's perspective, imagination is activated to draw a picture of the product's shape and nature, in relation to the identified problem. Students then consider what materials and tools they need, where they can be obtained, how much they cost, how they can be

assembled, and so on, regarding the elements they may need in the design. The teacher then allows the groups to present their work, the selected scenario, the identified problem(s), and their proposed solution as a team.

Constructive feedback is exchanged between the groups, and some ideas may be modified, changed, or developed based on peer feedback, providing an additional opportunity for collaborative learning. Students then bring all the necessary materials, tools, and supplies to build their proposed design to the classroom for the next meeting. The teacher confirms this and explains that the next step is for each group to begin implementing the product, reminding them to utilize technology and use environmentally friendly, recyclable materials (Al-Hattami & Bawaneh, 2025).

At the end of the meeting, each group presented its prototype to the class. Students began working on the design according to the plan they previously developed. The teacher visited the groups, providing support, observations, and feedback, answering their questions, and guiding them on how to solve challenges they faced without directly presenting solutions. At the end of the meeting, each group was given time to present the prototype to their classmates and receive feedback and questions from their classmates and the teacher. It is the duty of every group member who presents their work to respond to questions and provide clarification. This will lead to numerous comments and suggestions for improving the product. During this phase, students presenting their products will also explain their thinking to their classmates during the presentation, indicating that they will be adding and refining some aspects, particularly technological features, and sometimes the aesthetics and final product design.

The teacher assigns students to work on creating the items for the final presentation at the following meeting, once each group has finished presenting their work. All finished work is developed by students outside of class and presented at the next meeting. This also provides feedback and reinforces to students that development is an ongoing process (Al-Hattami & Bawaneh, 2025). Through problem-solving and teamwork, students created an engineering model with a technological character in the previous stage. After completing the first and second phases, the instructor gradually relinquishes control of the learning process and allows the students to take the next step.

Stage three

In this stage, the teacher divides the students into groups of two or three and presents selected science lessons included in the elementary school curriculum, which students are expected to teach after graduation. Each group selects a lesson, and during the weekly lectures, the teacher guides the students so that each

Table 2. M and SD of student performance by teaching method and gender

Variable		N	M	SD
Teaching method	STEM	76	86.37	5.28
	Conventional	57	77.84	7.00
Gender	Male	52	82.13	7.74
	Female	81	83.09	7.18

group develops a comprehensive and professional lesson plan based on the focal points of scientific inquiry, technological and engineering design, problem-based learning, and the integration of cooperative learning, as previously described in the first and second stages.

Each group then develops a presentation and prepares everything necessary to implement the plan in front of their peers in the form of collaborative microteaching. In this collaborative microteaching context, groups prepare and deliver their lessons to their peers. According to the assigned roles, each student presents a portion of the lesson, ensuring coverage of the main points of scientific inquiry, engineering and technological design, problem-solving phases, and the integration of cooperative learning.

It is significant to highlight that, as part of their professional commitment, the group conducting the lesson assumes the role of teachers while the other peers act as primary school students. After implementation, each student self-reflects on their own teaching practices during the microteaching session, according to a template prepared by the instructor for this purpose. The student submits the reflection to the instructor within three days of implementing the microteaching session. It should be noted that this teaching methodology was presented to the study tools reviewers to ensure its validity. The procedures and steps were agreed based on their feedback and approval.

STUDY RESULTS

Assumptions associated with the normality and linearity of regression were examined. Based on the range of values suggested by George and Mallery (2000), it was found that the skewness and kurtosis values were close to zero, leading to the conclusion that the distribution of the results scores was close to a normal distribution. Additionally, the findings of this study did not violate the assumption of a linear relationship between the variables.

To answer the first study question, "What is the effectiveness of using the STEM approach on student teachers' performance in the science course compared to the conventional method, and does performance differ according to student's gender?" The researchers calculated the Ms and SDs for the students' performance in the study sample, as shown in **Table 2**.

Table 2 presents the Ms and SDs of students' performance according to teaching method and gender.

Table 3. ANCOVA results for teaching method and gender (controlling for pre-test)

	Source	Type III sum of squares	df	Mean square	F	Significance
Teaching method	Corrected model	3,076.835 ^a	2	1,538.418	48.421	.000
	Intercept	20,796.992	1	20,796.992	654.578	.000
	Pre-test	708.956	1	708.956	22.314	.000
	Method	2,376.749	1	2,376.749	74.807	.000
	Error	4,130.308	130	31.772		
	Total	917,147.000	133			
	Corrected total	7,207.143	132			
Gender	Corrected model	715.789 ^a	2	357.895	7.167	.001
	Intercept	21,240.653	1	21,240.653	425.379	.000
	Pre-test	687.099	1	687.099	13.760	.000
	Students' gender	15.703	1	15.703	.314	.576
	Error	6,491.354	130	49.933		
	Total	917,147.000	133			
	Corrected total	7,207.143	132			

As shown in **Table 2**, students taught using the STEM approach achieved a higher M score ($M = 86.37$, $SD = 5.28$) compared to those taught using the conventional method ($M = 77.84$, $SD = 7.00$), indicating a mean difference of 8.53 points in favor of the STEM approach.

With respect to gender differences, **Table 2** shows that female students obtained a slightly higher M score ($M = 83.09$, $SD = 7.18$) than male students ($M = 82.13$, $SD = 7.74$), with a small mean difference of 0.96 points. Although these descriptive results suggest variation in performance across teaching methods and, to a lesser extent, gender, inferential statistical analysis was required to determine whether these differences were statistically significant.

Accordingly, an ANCOVA analysis was conducted, and the results are presented in **Table 3**. **Table 3** presents the results of the ANCOVA analysis examining the effects of teaching method and gender on students' performance while controlling pre-test scores. As shown in **Table 3**, there was a statistically significant effect of teaching method on students' performance in favor of the STEM approach ($F = 74.81$, $p < .001$), indicating that students taught using the STEM approach significantly outperformed those taught using the conventional method after adjusting for prior achievement. The pre-test covariate was also statistically significant, confirming its influence on post-test performance.

In contrast, the results presented in **Table 3** indicate that gender did not have a statistically significant effect on students' performance ($F = 0.31$, $p = .576$) when controlling pre-test scores.

This finding can be explained by the distinctive features of the STEM teaching method employed in this study, which guided the redesign and application of the scientific content. The primary objectives of the first phase's content reconstruction, aligned with the focal points of scientific inquiry, included observing and questioning students' immediate environment, conducting basic investigations, planning investigations, gathering and analyzing data, relating data to

mathematics, drawing and interpreting scientific conclusions, and providing structured opportunities for discussion.

The second phase integrated problem-solving strategies and design thinking into the design of a product, device, or prototype through structured steps based on collaborative work, divergent thinking, and convergent thinking during group brainstorming. The models were then designed, constructed, and tested, followed by iterative refinement based on constructive feedback from peers and the course instructor. These procedures provided a rich and meaningful learning experience that enhanced student learning and promoted higher-order thinking skills.

To answer the second research question, "What are the students' perceptions of the STEM approach in terms of its strengths, and Is it appropriate for student learning?" The researchers carefully crafted the open-ended questions posed to the students, ensuring their answers focused on the main ideas associated with each question. Based on this, the researchers agreed to consider these questions as the themes within the qualitative section of the study. The qualitative data related to student feedback on the questions posed to them were as follows:

The first sub-question focused on students' views regarding whether the STEM approach is appropriate for learning science and whether it stimulates higher-order thinking skills. The question asked was: "Do you think that teaching using the STEM approach is appropriate for students, and does it stimulate higher-order thinking skills? Please explain your perspective." A total of 65 out of 76 students (85.5%) responded to this question. Reviewing their responses, the results showed that 3 out of 65 respondents (approximately 5%), answered "no." They justified their responses by stating that the STEM approach is challenging and complex and that, in their opinion, it focuses on lesson-specific concept rather than the entire curriculum. They also indicated that they have no desire to implement it with

their students in the future noting that the study sample consisted of college of education students who are preparing to become first-cycle teachers. In contrast, 63 out of 65 students, representing approximately 95%, answered "yes." According to an analysis of the responses, these students supported the STEM approach for several reasons, including that it enhances critical thinking and problem-solving skills by integrating multiple disciplines and their real-world applications. They also highlighted the opportunities it provides for collaborative learning and peer feedback on the strengths and weaknesses of the designed products. Some students noted that STEM-based teaching is student-centered, with students actively deriving and achieving learning objectives. They reported that the engaging presentation of content increases class effectiveness by actively involving students. Others point out that the STEM approach encompasses multiple subjects, stimulating student skills such as critical and higher-order thinking. They further emphasized that the teacher's role should primarily be that of a facilitator, while students remain at the center of the learning process. Others explained that learning through the STEM approach is enjoyable due to active participation in activities and practical experiments. They noted that this approach enhances students' ability to solve real-life problems, thereby preparing them for future challenges. Several responses also contended that teaching STEM subjects encourages educators to think more creatively and scientifically in order to present science in an engaging and motivating manner.

Regarding the second sub-question, "What are the strengths of the STEM-based course, in your personal opinion?" a total of 65 out of 76 students (85.5%) responded to this question. The most significant strength of the course, from their perspective, was that the course design enabled students to think critically about and interpret phenomena in their surrounding environment through self-discovery. The instructor merely guided the investigation and design processes acting as a facilitator and supporter of students' learning. One student stated, "This is one of the courses I have enjoyed most during my college studies, as it includes scientific experiments that not only help my students understand the content more easily, but also increase enjoyment and motivation to attend subsequent lectures. The course also addresses interesting topics that college students can benefit from during practical training and later in their professional careers as teachers." Others pointed out that this course emphasis on making the learning process student-centered sets it apart. They reported observing the positive effects of student-centered learning during short practical training experiences. In addition, some students believed the course provided them with a distinctive pedagogical approach to teaching science as future teachers. One of the best teaching strategies for both students and teachers is this approach, which is

focused on inquiry-based experiments, problem-solving, and technological design. According to several respondents, the abundance of experiments and practical applications in the course promotes deeper learning and improves information retention, which they identified as a key strength of the STEM approach.

one student stated that the STEM curriculum is more than just academic learning; it is a lifestyle that helps students develop the skills needed to become future changemakers. This student emphasized that "It is a major change in contemporary education due to its emphasis on creativity, critical thinking, and practical application. According to several students one of the key strengths of the STEM curriculum's, is the nature of its assignments, which effectively assess students' mastery of course content. Practical application, observation, and ongoing reflection on the subject matter are key components of these tasks. Other students highlighted additional strengths of the course in several areas. They noted that the course content, which included numerous physics, chemistry, and biology experiments linked to everyday life, was particularly beneficial.

As a result, students reported being able to think more deeply and creatively. For instance, one student explained that they were able to design tools using recycled materials, an experience they had not encountered previously. Even though there were some difficulties, students described the design process and teamwork as enjoyable and motivating. Lastly, one student noted that this method provides students with a comprehensive understanding of science instruction. "To be honest, when we usually think about explaining science, we do not consider it from the perspective of scientific inquiry and technological engineering design," the student explained. As a result, the course offers a solid and clear basis that aids in students' understanding of the subject before, during, and after planning, execution, and evaluation.

The third sub-question focused on students' attitudes toward science and asked: "Have your attitude and view of science changed because of taking this course? How?" This question was answered by 65 out of 76 students (85.5%). Out of the 65 students, only one student responded "no," stating that they had previously studied science in this manner. this student was aware of the value of design and inquiry in science education and how it relates to everyday life but reported that the course mainly reinforced this prior understanding. A responding student remarked, "Some of the experiments we conducted were impactful. They helped me understand the depth of the subject and expanded my knowledge of science." However, the same student noted that some activities, such as the soil experiment, were relatively simple and had a limited impact. This suggests that some disciplines might benefit from the STEM approach while others might not. In contrast, 63 out of 65 students (approximately 97%) answered "yes.."

An examination of the replies shows that they reported a favorable shift in their opinions and attitudes regarding science.

The students agreed that their understanding of science had undergone a significant shift after finishing the course. One student reported that their perspective shifted from a one-dimensional and superficial understanding of science to recognizing that science requires methodical research and systematic progression from simple to complex concepts. Another student clarified that they have come to recognize the richness of science, which includes mathematics, technology, engineering, discovery, and design, and no longer viewed it as limited to experiments and theoretical knowledge. Lastly, a third student reported that their understanding of science has grown beyond the confines of physics, chemistry, and biology, demonstrating its integration with engineering, technology, and mathematics, thus providing students with a more expansive and holistic perspective

Another student mentioned that their high school education was focused on the humanities and they had limited prior exposure to science. The student added that although they had previously disliked science, this course changed their viewpoint. The student stated, "My experiences and the way the material was presented made me reconsider science. It rekindled my enthusiasm for science. This was supported by another student, who stated, "My perspective on science underwent a significant transformation during the STEM course. I now see it as an essential field with many opportunities for growth and innovation that is closely connected to daily life." The student further noted an increased appreciation for continuous learning and research, emphasizing that science is not static knowledge but a means to understand and improve the world. From another perspective, one respondent explained "Yes, my outlook and attitudes have changed for the better. I used to think that teaching science wasn't fun, especially since I'll be teaching young children (grades 1-3) in the future and realized that engaging them requires innovative and modern teaching methods. Therefore, I learned how to design effective and engaging experiments that can be integrated into the curriculum. I also learned how to effectively integrate theoretical and practical content." Another respondent confirmed a significant change in their outlook on science, saying, "Yes, absolutely. I used to think science was a difficult and dry subject for students, but after this course, I realized that teachers can be creative in science classes and make them among the most engaging lessons." Another student indicated that the reason for their changed attitudes toward science was that the STEM approach seeks to solve real-life problems from students' lives, while another indicated that employing scientific inquiry and engineering design makes lessons enjoyable and helps overcome boredom and routine. One student with a humanities background

and no prior exposure to science courses also reported a positive shift in attitude, stating that the course experiences and teaching methods led them to reconsider science and rekindle their interest in the subject.

Lastly, the fourth sub-question focused on enhancing the instructional and learning methods used in the course. It asked, "If you were the course instructor, what would you change to improve the course and make it more enjoyable and beneficial in the future?." Students' responses varied. In terms of involving students and energizing their role as the center of the teaching and learning process, most students said that the practices used were of high quality. These practices included inquiry experiences, the implementation of scientific inquiry focal points, the use of engineering and technological design to solve real-world problems, the activation of collaborative work, and creating opportunities for students to share ideas, offer feedback, and benefit from one another's knowledge and experience, all while making learning enjoyable. However, students also provided several recommendations for improvement, which can be summarized as follows:

- Focusing more on the details of engineering and technological designs rather than quantity-emphasizing quality over quantity.
- Choosing topics and issues outside the Ministry of Education curriculum—or selecting global issues rather than local ones.
- Reducing the amount of scientific material presented and avoiding detailed exploration of scientific details.
- Recommendations for altering assessments methods include substituting the midterm exam with individual reflection using group or paired reflection instead of individual reflection on the instructor's model lesson.
- Opening the door to technological development for students according to their interests, without restricting them to physical, biological, and digital technologies.
- Organizing field visits to engineering companies and science centers to inspire students and introduce them to real-world applications of science.
- Integrating gamification within the STEM curriculum.

DISCUSSION AND RECOMMENDATIONS

There are several reasons underlying the study's findings. The STEM approach, which emphasizes skill development and embraces diversity and differentiation, is a useful starting point for the

educational process. Additionally, it engages the local community and environment, addresses real-world issues, and links the educational process to students' experiences. Moreover, by giving constructive feedback at different learning stages, the instructor plays a crucial role as a facilitator of student learning. This method places a strong emphasis on the active and pivotal role of the learner, who shares experiences, learns from practice and peers, and constructs knowledge and skills (Al-Ghamdi, 2018; Akcan et al., 2023; Allan, 2019; Al-Qadi, 2019; Kazu & Alçin, 2021; Rogovaya et al., 2019).

Additionally, the STEM approach is predicated on the notion of bridging gaps and creating links across diverse disciplines to integrate multiple domains of knowledge (STEM). Within this framework, this method depends on several techniques, including project-based learning, inquiry-based learning, engineering and technological design, problem-solving and design thinking, and brainstorming, which incorporates both divergent and convergent thinking (Bawaneh & Malkawi, 2023; Chonkaew et al., 2016; Rahayu et al., 2018; Singh et al., 2021). In each of these processes, students' capacity to recognize cause and effect relationships, observe phenomena, and describe objects and their properties is continuously questioned and developed.

This approach is divided into multiple phases. In the first phase, the instructor uses a modeling approach by directing and carrying out activities, which include setting up all the supplies and requirements needed to convey the scientific content. This entails using the focal points of scientific inquiry and carrying out inquiry-based experiments with the students in groups while utilizing appropriate supplies and equipment. Additionally, the teacher collects and analyzes the data, relates it to mathematics, and draws conclusions for each group based on the data gathered and their interpretations (Cheng et al., 2024; Chin & Larwin, 2022; Margot & Kettler, 2019).

The instructor then initiates a constructive discussion in which all groups express their ideas and interpretations and provide constructive feedback to one another. This phase represents a significant opportunity for students to learn from one another, enhances their self-confidence, and helps them appreciate the value and benefits of science and its relationship to the natural world (Cheng et al., 2024; Parno et al., 2021). This is followed by the second phase, which relies on applying knowledge and skills aligned with the targeted learning outcomes by enhancing students' skills in engineering and technological design using problem-based learning and design thinking, as well as encouraging collaborative group work. In the third phase, the teacher divides students into groups, and each group selects a lesson from the science curriculum (Rahayu et al., 2018; Singh et al., 2021). During weekly lectures, the teacher guides students to develop a professional lesson plan

based on the focal points of scientific inquiry, engineering and technological design, problem-based learning, and collaborative learning, as described above. Each group then develops a presentation and prepares all necessary materials to implement the plan in front of their peers in the form of a microteaching session. Following the implementation process, each student self-reflects on their individual teaching practices—during the microteaching session (Chin & Larwin, 2022; Margot & Kettler, 2019). Furthermore, the findings indicate no statistically significant differences attributable to gender. This result is considered logical in a learning environment where opportunities, facilities, and capabilities are equal for both males and females, for teachers as well as students. In addition, school environment lifestyle, social, economic, and cultural conditions as well as infrastructure do not differ between boys' and girls' schools, which operate under comparable conditions. Furthermore, all teachers, regardless of gender, follow the same regulations and policies and enjoy the same moral and material benefits (Al-Ghamdi, 2018; Allan, 2019; Al-Malki, 2018; Bawaneh & Malkawi, 2023).

While the findings of this study provide strong evidence for the effectiveness of the STEM-based course in preparing preservice teachers, they should be interpreted with caution. The study was conducted at a single university within the Arabian Gulf region, which limits the generalizability of the results to other higher education contexts. Differences in institutional structures, teacher preparation models, cultural expectations, and technological infrastructure may influence the implementation and outcomes of STEM-based instruction. Therefore, the findings should not be overgeneralized beyond contexts with similar educational, social, and cultural characteristics.

Future research should extend this work through multi-institutional and cross-national studies to examine the effectiveness of STEM-based teacher preparation programs across diverse educational systems. Comparative studies involving universities from different regions could provide deeper insights into how contextual variables influence preservice teachers' learning outcomes, professional readiness, and perceptions of STEM-based pedagogy. Such studies would strengthen the external validity of current findings and contribute to the development of scalable and adaptable STEM models in teacher education.

Recent international research further supports the relevance of STEM-based and digitally enriched pedagogical approaches in teacher education. Studies have demonstrated that integrating digital tools, artificial intelligence, and innovative instructional strategies enhances preservice teachers' professional competencies, motivation, and pedagogical adaptability (AlAli & Wardat, 2024; Aldalalah et al., 2025; Garcia et al., 2026). Cross-national investigations have also shown

that teachers' attitudes toward modeling, problem-solving, and technology integration vary across contexts, highlighting the importance of culturally responsive and institutionally supported STEM implementation (Wardat et al., 2025; Winaryati et al., 2025). These findings align with the present study and suggest that STEM-based teacher preparation can play a critical role in fostering sustainable educational innovation when supported by appropriate policy, infrastructure, and professional development frameworks.

CONCLUSION

Through this comprehensive journey, the researchers conclude that the STEM approach is effective in enhancing student learning and professionally preparing future teachers in an engaging manner. This approach engages students at the center of the teaching and learning process in the production and use of knowledge and enhances their teaching skills in creating innovative activities that integrate science, technology, and mathematics with engineering. This is because the learner progresses through phases that align with the elements of the STEM approach: scientific inquiry, engineering and technological design, problem-based learning, and design thinking. Additionally, collaborative learning is embedded throughout each of these phases. Accordingly, the study recommends providing professional development training to teachers on how to apply the STEM approach in the classroom and integrating STEM-based methodologies into teacher preparation programs at all educational levels. Furthermore, it is necessary to restructure curricula and instructional content in accordance with the principles of this approach and provide the necessary materials, tools, and devices in schools to support the implementation of hands-on activities, experiments, and diverse design-based learning experiences.

Author contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

Funding: No funding source is reported for this study.

Ethical statement: The authors stated that the research was conducted in an educational context and did not require formal ethical approval under the institution's policy, as it involved anonymous, voluntary participation without any risk to participants. Written informed consents were obtained from study participants.

AI statement: The authors stated that the generative AI tools were used to check the clarity of English for some paragraphs only. The AI did not perform any content generation.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

- Abu Musa, A. (2019). *The effectiveness of a science unit designed according to the integrated (STEM) approach in developing scientific practices among ninth-grade female students* [Master's thesis, Islamic University of Gaza].
- Adebayo, A. (2022). Science, technology, engineering and mathematics (STEM) as an enabler for development and peace, office of the special adviser on Africa United Nations. *United Nations*. https://www.un.org/osaa/sites/www.un.org.osaa/files/docs/2116613_stem_policy_paper_web_rev.pdf
- Akcan, A. T., Yildirim, B., Karataş, A. R., & Yılmaz, M. (2023). Teachers' views on the effect of STEM education on the labor market. *Frontiers in Psychology*, 14. <https://doi.org/10.3389/fpsyg.2023.1184730>
- AlAli, R., & Wardat, Y. (2024). How ChatGPT will shape the teaching learning landscape in future. *Journal of Educational and Social Research*, 14(2), 336-345. <https://doi.org/10.36941/jesr-2024-0047>
- Al-Amoudi, H. S. (2017). Pre-service science education teachers in Umm Alqura University perceptions around the "STEM" approach and its relationship to performance in the teaching of practical education. *Umm Al-Qura University Journal of Educational and Psychological Sciences*, (8), 87-142. https://drive.uqu.edu.sa/_/jep/files/%D8%A7%D9%84%D9%85%D8%AC%D9%84%D8%A9%20%D9%83%D8%A7%D9%85%D9%84%D8%A9.pdf
- Aldalalah, O. M. A., Wardat, Y., Al-Omari, A. A. H., & Khodair, R. M. (2025). The effectiveness of interactive digital content based on the TPACK model in developing the skills of educational aids production and improving cognitive achievement among early childhood university students. *Contemporary Educational Technology*, 17(2), Article ep572. <https://doi.org/10.30935/cedtech/16046>
- Al-Deghaim, K. (2017). Pre-service science teachers' cognitive structures regarding fields of stem "science, technology, engineering, mathematics" and science education, studies in curricula and teaching methods. *Egyptian Society for Curricula and Teaching Methods*, (226), 86-121. <https://search.emarefa.net/detail/BIM-1222505>
- Al-Ghamdi, M. A. (2018). The effect of sustained digital storytelling on developing creative thinking among intermediate school female students. In *Proceedings of the 8th Conference for the Development of Arab Education*.
- Al-Hattami, A., & Bawaneh, A. (2025). The effect of lesson study approach on developing teachers' reflective thinking as a self-assessment tool. *International Journal of Evaluation and Research in*

- Education*, 13(5), 3306-3313. <https://doi.org/10.11591/ijere.v13i5.29354>
- Al-Kellani, A., & Al-Shraifeen, N. (2016). *Introduction to research in education and social sciences*. Dar Al Masirah for Publishing Distribution and Printing.
- Allan, A. (2019). *The effectiveness of using digital storytelling in developing second-grade Arabic language reading skills and motivation* [Master's thesis, Middle East University].
- Al-Malki, M. (2018). The effect of teaching science by using STEM approach in developing research skills in accordance with the ISEF standards among primary stage students. *International Journal of Educational and Psychological Studies*, 4(1), 113-135. <https://doi.org/10.31559/EPS2018.4.1.7>
- Almutairi, N. M. (2023). The effectiveness of an enrichment teaching program based on STEM approach in developing the 21st skills of intermediate school students. *Journal of Educational and Psychological Sciences*, 7(44),66-81. <https://doi.org/10.26389/AJSRP.R0709232023>
- Al-Qadi, A. M. (2019). *The STEAM approach: Its philosophy, objectives, student learning levels, and applications in the curriculum*. Dar Al-Kitab Al-Tarbawi for Publishing and Distribution.
- Amin, M., Jalal, S., & Amin, H. (2022). Influence of 21st century learning skills on students' academic performance: Evidence from university context. *Journal of Educational Research and Social Sciences Review*, 2(1), 39-44. <https://ojs.jerssr.org.pk/index.php/jerssr/article/view/54/25>
- Ayverdi, L. & Öz Aydın, S. (2020). Meta-analysis of studies examining the effect of STEM education on academic success. *Necatibey Faculty of Education Electronic Journal of Science, and Mathematics Education*, 14(2), 840-888. <https://doi.org/10.17522/balikesirnef.755111>
- Bawaneh, A. K., Rabab'h, B. S., Al-Salman, S. M., & Alghazo, Y. M. (2024). Science and math teachers' satisfaction level towards electronic educational supervision. *International Journal of Information and Education Technology*, 14(3), 372-381. <https://doi.org/10.18178/ijiet.2024.14.3.2059>
- Bawaneh, A., & Alnamshan, M. (2023). Design thinking in science education: Enhancing undergraduate students' motivation and achievement in learning biology. *International Journal of Information and Education Technology*, 13(4), 621-633. <https://doi.org/10.18178/ijiet.2023.13.4.1846>
- Bawaneh, A., & Malkawi, E. (2023). STEM faculty members' perspectives and challenges towards distance learning and virtual classes during COVID-19 outbreak. *Turkish Online Journal of Distance Education*, 24(1), 246-261. <https://doi.org/10.17718/tojde.958068>
- Bawaneh, A., Al-Salman, S., Salem, T., & Altarawneh, A. (2025). AI Shaping the future of education: Science and math teachers' satisfaction level and motivating factors towards integrating artificial intelligence in teaching and learning. *International Journal of Information and Education Technology*, 15(3), 496-509. <https://doi.org/10.18178/ijiet.2025.15.3.2261>
- Bawaneh, A., Moumene, A., & Aldalalah, O. (2020). Gauging the level of reflective teaching practices among science teachers. *International Journal of Instruction*, 13(1), 95-112. <https://doi.org/10.29333/iji.2020.13145a>
- Briny, L., & Hill, J. (2013). *Building STEM education with multinationals* [Paper presentation]. The International Conference on Transnational Collaboration in STEAM Education.
- Bruning, R. H., Schraw, G. J., Norby, M. M., & Ronning, R. R. (2004). *Cognitive psychology and instruction*. Pearson.
- Bureau, H. (2015). Promotion of STEM education- Unleashing potential in innovation. *Curriculum Development Council*. <http://www.edb.gov.hk/attachment/en/curriculum>
- Cheng, M. F., Lo, Y. H., & Cheng, C. H. (2024). The impact of STEM curriculum on students' engineering design abilities and attitudes toward STEM. *International Journal of Technology and Design Education*, 34, 1805-1833. <https://doi.org/10.1007/s10798-024-09883-9>
- Chine, D. R., & Larwin, K. H. (2022). Longitudinal study using hierarchical linear modeling of student and school effects on academic achievement in a middle school STEM program. *Journal of Research in STEM Education*, 8(1), 1-23. <https://doi.org/10.51355/jstem.2022.108>
- Chonkaew, P., Sukhummek, B., & Faikhamta, C. (2016). Development of analytical thinking ability and attitudes towards science learning of grade-11 students through science technology engineering and mathematics (STEM education) in the study of stoichiometry. *Chemistry Education Research and Practice*, 17(4), 842-861. <https://doi.org/10.1039/C6RP00074F>
- Dagger Jr, W. E. (2013). Evolution of STEM in the United States. *International Technology and Engineering Educators Association*. <http://www.iteea.org/Resources/PressRoom/AustraliaPaper.pdf>
- English, L. (2016). STEM education K-12 perspective on integration. *International Journal of STEM Education*, 3(3), 1-8. <https://doi.org/10.1186/s40594-016-0036-1>
- Garcia, M. B., Acut, D. P., Arif, Y. M., Maher, D., Alex, J. K., Wardat, Y., & Damaševičius, R. (2026). Modernizing mathematics education with artificial

- intelligence: A narrative review of AI-powered tools, thematic trends, and instructional applications. In A. Mazı (Ed.), *The convergence of mathematics and AI: A new paradigm in education* (pp. 153-186). IGI Global. <https://doi.org/10.4018/979-8-3373-1998-8.ch006>
- George, D., & Mallery, P. (2000). *SPSS for windows step by step*. Allyn and Bacon.
- Hattie, J., & Zierer, K. (2025). *Visible learning: Lesson planning: An evidence-based guide for successful teaching*. Routledge. <https://doi.org/10.4324/9781003051701>
- Hussain, F. (2021). *The effectiveness of employing the STEAM approach in developing the audio reading and speaking skills of fourth-grade female students* [Unpublished master's thesis]. Islamic University of Gaza.
- Kazu, I., & Alcin, C. (2021). The effect of stem education on academic performance: A meta-analysis study. *The Turkish Online Journal of Educational Technology*, 20(4), 101-116. <https://files.eric.ed.gov/fulltext/EJ1313488.pdf>
- Lantz Jr, H. B. (2009). Science, technology, engineering, and mathematics (STEM) education: What form? What function? *UASTEM*. <http://www.currttechintegrations.com/pdf/STEMEducationArticle.pdf>
- Mahmoud, E., & Bawaneh, A. (2025). Best practices of effective classroom management strategies supported by digital ICT in higher education. *International Journal of Evaluation and Research in Education*, 14(3), 2337-2345. <https://doi.org/10.11591/ijere.v14i3.32178>
- Margot, K., & Todd Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, 6, Article 2, <https://doi.org/10.1186/s40594-018-0151-2>
- Ministry of Education. (2010). The U.S. Department of Education. *Ministry of Education*. <https://www.ed.gov/>
- Muhammad, I., & Makhdoom, A. (2022). Impact of STEMs in the secondary school teaching process. *Voyage Journal of Educational Studies*, 2(1), 23-33. <https://doi.org/10.58622/vjes.v2i1.11>
- Obiedat, D., Kayed, A., & Adass, A. (2016). *Scientific research: Understandable tools and methods*. Dar Alfiker Publishers and Distributors.
- Parminder, K. (2019). *Supports for persistence in STEM: Student and parent perspectives of an inclusive STEM high school* [PhD thesis, Azusa Pacific University].
- Parno, E., Supriana, A., Widarti, N., & Ali. M. (2021). The effectiveness of STEM approach on students' critical thinking ability in the topic of fluid statics. *Journal of Physics: Conference Series*, 1882, Article 012150. <https://doi.org/10.1088/1742-6596/1882/1/012150>
- Radwan, O. (2019). Science, technology, engineering, and mathematics (STEM) schools in the United States of America and Egypt: A comparative study. *Journal of Comparative and International Education*, (12).
- Rahayu, T., Syafrilb, S., Pahrudinb, A., Satarc, I., Halima, L., & Erlina, N. (2018). Mini review: Improving teachers' quality in STEM-based teaching learning in secondary school. In *Proceedings of the 5th International Conference on Islam and Higher Education*. <https://doi.org/10.31219/osf.io/pnc3u>
- Rogovaya, O., Larchenkova, L., & Gavronskaya, Y. (2019). Critical thinking in STEM (science, technology, engineering, and mathematics). *Utopía y Praxis Latino Americana*, 24(6). <https://www.redalyc.org/journal/279/27962177005/html/>
- Salha, H. (2022). *The effectiveness of employing the STEAM approach in developing mathematical communication skills and problem solving among fourth-grade students* [Unpublished master's thesis]. Islamic University of Gaza.
- Sanders, M. (2009). STEM, STEM education, STEM mania. *VTechWorks*. <https://vtechworks.lib.vt.edu/server/api/core/bitstreams/b5f37b87-c914-4e5a-8abc-f9b491dc2e36/content>
- Singh, R., Nieves, H. I., Singh, E. R., & Dietiker, L. (2021). Impact of lesson design on teacher and student mathematical questions. In *Proceedings of the Psychology of Mathematics Education*.
- Stephanie, P. M. (2008). Blessed unrest: The power of unreasonable people to change the world. *NCSSMST Journal*, 13(2), 8-14.
- Thomasian, J. (2011). Building a science, technology, engineering, and math education agenda: An update of state actions. *NGA Center for Best Practices*. <https://eric.ed.gov/?id=ED532528>
- Wahono, B., Lin, P. L., & Chang, C. Y. (2020). Evidence of STEM enactment effectiveness in Asian student learning outcomes. *International Journal of STEM Education*, 7, 1-18. <https://doi.org/10.1186/s40594-020-00236-1>
- Wardat, Y., Hidayat, R., Belbase, S., Al-Shraifin, A. A., & Alribdi, N. I. (2025). Cross-national comparison of mathematical modelling attitudes among educators. *European Journal of Education*, 60(4), Article e70288. <https://doi.org/10.1111/ejed.70288>
- Winaryati, E., Wardat, Y., Setiawan, A., Iksan, Z. H., Rauf, R. A. A., Kusumaningrum, W. I., & Nurdiana, L. (2025). Developing 21st century skills through STEM-based lesson study and project-based approaches in chemistry learning. *Educational*

Process: *International Journal*, 19, Article e2025534.

<https://doi.org/10.22521/edupij.2025.19.534>

<https://www.ejmste.com>