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Research paper

The Effectiveness of a STEM-Based Instructional Unit in Developing Problem-Solving Skills among Students

Abdelrahim Fathy Ismail [1]*, Khaled Ahmad Obeidat [2], Afaf Abdelah Othman [3], Alaaeldin Ahmed Hamid [1]

[1] *King Faisal University,* SAUDI ARABIA
[2] *Ajloun National University,* JORDAN
[3] *Najran University,* SAUDI ARABIA

***Corresponding Author:** afismail@kfu.edu.sa

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ABSTRACT

STEM education has become a cornerstone of 21st-century learning, sparking curiosity, creativity, and practical reasoning in young learners. In the early primary grades, STEM-based approaches help students bridge the gap between different disciplines and apply their knowledge to real-life challenges. This study aimed to design and implement a STEM-based instructional unit for grades one to three in Saudi elementary schools, examining its effectiveness in developing problem-solving skills across four key areas: identifying the problem, generating possible solutions, implementing those solutions, and evaluating the outcomes. Adopting a quasi-experimental design, the study involved 46 students randomly selected from three public elementary schools in Al-Ahsa, Saudi Arabia. The intervention consisted of a nine-lesson unit that integrated science, mathematics, engineering, and technology through activities tailored specifically to the developmental level of young learners. Data were collected using an oral problem-solving test aligned with STEM processes. The findings revealed that the STEM-based unit significantly boosted students' overall problem-solving abilities. The most notable gains were seen in implementation skills, followed by problem identification, solution generation, and finally evaluation skills. These results suggest that hands-on, exploratory learning fosters a child's ability to apply and test their ideas even before they can systematically assess them. Ultimately, the study highlights how STEM-integrated learning cultivates inquiry, reasoning, and confidence in tackling real-world problems from the very start of schooling. Looking ahead, these results underscore the importance of expanding STEM instruction in Saudi primary education through teacher training and curriculum innovation.

Keywords: STEM, problem-solving skills, early primary education, inquiry-based learning, creative thinking

In the early years of primary education, STEM (Science, Technology, Engineering, and Mathematics) is not introduced as an additional subject, but rather as a way of learning and thinking. It provides children with opportunities to connect ideas across disciplines and to explore the world as a meaningful whole (English, 2017; Siregar, 2025). Through inquiry, observation, experimentation, reasoning, and reflection, young learners begin to understand how knowledge applies to real-life contexts rather than isolated topics in a textbook (Zhou et al., 2019).

Recent research emphasizes that introducing STEM principles at the primary level effectively channels children's natural curiosity into purposeful learning. Simple, age-appropriate activities-such as building small bridges, designing circuits, or measuring distances-allow children to connect abstract concepts in mathematics and science with their tangible experiences. These playful investigations cultivate both conceptual understanding and joy in discovery (Way et al., 2022; Aydın, 2020; Kotsis, 2025; Al-Hinai et al., 2026).

STEM-based learning also nurtures inquiry skills, design thinking, and problem-solving abilities, while strengthening children's social and communication skills through teamwork and dialogue (Safiee et al., 2018). As pupils collaborate, they learn to explain their reasoning, share ideas, and refine their solutions collectively. In doing so, they also develop linguistic and cognitive flexibility-learning to describe processes, justify choices, and draw logical conclusions (Goodnough et al., 2014; Osman et al., 2026).

The success of STEM education, however, depends largely on teachers' readiness and professional growth. Teachers in early primary grades are not merely transmitters of knowledge; they are designers of learning experiences who weave play, discovery, and application together (Keleman et al., 2021). Effective professional development-rooted in observation, reflection, and classroom experimentation-empowers educators to confidently implement integrated STEM practices (Averin et al., 2020).

STEM in the early grades is not simply about teaching science early; it is about cultivating lifelong habits of mind asking questions, testing ideas, revising one's thinking, and seeking meaning in the connections between disciplines. By helping children see learning as a coherent journey rather than a set of separate lessons, STEM builds a foundation for creativity, resilience, and curiosity that extends far beyond the classroom.

Recent international studies have consistently underscored the transformative potential of STEM learning in the early years of primary education. Way et al. (2022) demonstrated that structured, level-based STEM programs can help children build progressively deeper conceptual understanding, promoting both cognitive and creative growth in primary classrooms. Similarly, Wan et al. (2023) explored the theoretical and practical dimensions of STEM integration, emphasizing that successful implementation requires coherent planning, teacher readiness, and alignment between curriculum design and real-life contexts. Safiee et al. (2018) showed that project-based inquiry learning, even with very young students, enables children to grasp foundational scientific and engineering ideas-such as magnetism-through hands-on experimentation and guided questioning. Supporting this, KAREN Goodnough et al. (2014) found that sustained, reflective professional development is vital to help primary teachers confidently adopt integrated STEM pedagogies and manage classroom challenges creatively. Complementing these findings, Ibraeva and Shaushekova (2023) revealed that supplementary educational activities significantly boost students' interest and motivation toward STEM subjects, especially when learning environments encourage curiosity and real-world application.

Problem-solving in early childhood is much more than a technical ability or a classroom routine; it represents a natural way of thinking, learning, and interacting with the surrounding world (Chen, 2025; Ormancı, 2026). When children are encouraged to explore, ask questions, and test their ideas, they begin to view challenges not as barriers but as chances to understand how things work and how they can make them better. In this sense, problem-solving becomes the heartbeat of learning, combining curiosity, reasoning, creativity, and persistence in meaningful ways (Santos et al., 2024).

Problem-solving is one of the most essential cognitive and social skills that begins to form in early childhood and continues to evolve throughout the school years (Lesh et al., 2013). It is not a single ability but a dynamic process that integrates observation, reasoning, decision-making, creativity, and reflection. As children encounter challenges whether assembling blocks, resolving a peer conflict, or interpreting a story problem they learn to plan, test ideas, and adapt when initial attempts fail (Sangngam, 2021). According to Ömeroğlu et al. (2009), teachers in both preschool and primary settings recognize that fostering problem-solving from an early age builds the foundation for lifelong learning and self-regulation.

In the early grades, these skills develop across four interrelated dimensions: identifying a problem, generating possible solutions, implementing a chosen strategy, and evaluating its effectiveness. Lesh et al. (2013) highlighted that children's mathematical and scientific understanding grows most effectively when they are given authentic, open-ended problems that require them to reason and experiment rather than memorize procedures. Similarly, Yurtseven et al. (2021) found that decision-making and problem-solving skills are strongly correlated in primary school students those who are encouraged to make choices tend to demonstrate higher persistence, flexibility, and confidence when confronting complex tasks.

Beyond the cognitive domain, problem-solving nurtures social and emotional development. Mulrey (2017) showed that structured programs aimed at social problem-solving in early childhood improved empathy, communication, and self-regulation, allowing children to manage conflicts more constructively. Özbey (2017) similarly linked value-based behavior-such as cooperation and respect-to improved problem-solving ability, suggesting that moral and cognitive growth progress hand in hand. These findings emphasize that teaching young children how to think and resolve issues is as crucial as teaching them what to learn.

In recent years, the connection between problem-solving and STEM learning has become more prominent. Sangngam (2021) demonstrated that creative problem-solving can be meaningfully enhanced through STEM-based activities, where children explore, design, and evaluate ideas in real-world contexts. Inci Kuzu (2021) also revealed that even during the disruptions of the COVID-19 pandemic, students who engaged in problem-oriented learning activities retained stronger positioning and reasoning skills, underscoring the resilience that problem-solving fosters.

At a broader level, Chen (2025), and Arianto and Hanif (2024) confirmed that problem-solving ability is closely tied to metacognitive awareness, self-regulation, and mathematical understanding all core elements of early academic success. Santos et al. (2024) further emphasized that when children are given opportunities not only to solve but also to pose problems, they develop multiple literacies-linguistic, mathematical, and scientific-that support their overall intellectual growth. Meanwhile, Getenet (2024) argued that modern tools such as ChatGPT can be incorporated into multistrategy problem-solving frameworks, helping teachers design tasks that blend computational thinking with creative reasoning, especially in mathematics education.

Designing instructional units for young learners is both an art and a science. At the early primary level, it requires a thoughtful balance between structure and exploration, guidance and autonomy, simplicity and challenge. A well-designed STEM-based unit goes beyond assembling a collection of activities; it creates a coherent learning journey where children can question, investigate, build, and reflect in ways that make sense to them.

Research increasingly supports the idea that integrated units-especially those built on project-based or inquiry-based frameworks-help students connect conceptual understanding with real-world applications. Wieselmann et al. (2022) found that teacher-developed STEM project-based units were most successful when they incorporated open-ended investigations that required students to plan, test, and refine their ideas collaboratively. Similarly, Anwar et al. (2022) reported that integrated STEM curriculum units in life sciences led to deeper comprehension and longer retention of scientific ideas, as learners constructed their knowledge through experimentation rather than rote instruction.

An important consideration in the design of such units is the level of cognitive demand embedded in classroom tasks. Forde et al. (2023) highlighted that when mathematical thinking is explicitly woven into STEM activities, students engage more deeply with data, measurement, and reasoning, leading to improved problem-solving performance. Dare and Ring-Whalen (2024) further observed that the success of STEM units depends on how faithfully teachers implement them during daily practice; flexible adaptation, rather than rigid adherence, often results in richer learning experiences and stronger integration across subjects.

The process of designing effective STEM units also relies heavily on instructional usability and teacher capacity. White and Newby (2025) proposed an Instructional Approach Usability Scale to help educators evaluate the accessibility and coherence of their STEM lesson designs. Their findings suggest that usability-how intuitive, adaptable, and learner-centered an instructional unit is-can be just as critical as content accuracy. Halawa et al. (2024), in a systematic review of K–12 STEM instructional design, echoed this view, emphasizing that good design combines sound pedagogical principles with opportunities for creativity, collaboration, and iterative improvement.

Beyond the classroom level, Johnson et al. (2024) argued that designing effective STEM instruction requires professional development that connects pedagogy to real societal issues. When teachers design learning around authentic, socially relevant themes-such as sustainability, health, or digital innovation-students perceive learning as purposeful and connected to the larger world. This approach not only enhances motivation but also builds empathy and civic responsibility, aligning early STEM education with broader human and societal goals.

Despite the growing interest in STEM learning in primary education, much of the existing work still focuses on general outcomes or on older students. Studies often show that STEM can support thinking skills, but they rarely look closely at how young children in the first years of school actually deal with problems step by step. There is still limited attention to how problem-solving develops in early primary classrooms, especially when it is broken down into clear processes such as identifying the problem, suggesting ideas, trying solutions, and reflecting on results. There is also a need for studies that move beyond general descriptions and provide concrete classroom models that teachers can use. Many discussions highlight the value of STEM, but fewer studies show how a structured unit can be designed and tested with young learners in real school settings.

STATEMENT OF THE PROBLEM

Despite the growing recognition of STEM as a transformative approach to education, its integration in the early years of primary school remains limited and often superficial. In many classrooms, learning in the first three grades continues to follow traditional, subject-segregated models that emphasize memorization and routine exercises rather than curiosity, exploration, and authentic problem solving. This disconnect between the potential of STEM and its actual classroom presence means that many children are missing the opportunity to build the habits of inquiry, creativity, and persistence that should form the foundation of lifelong learning.

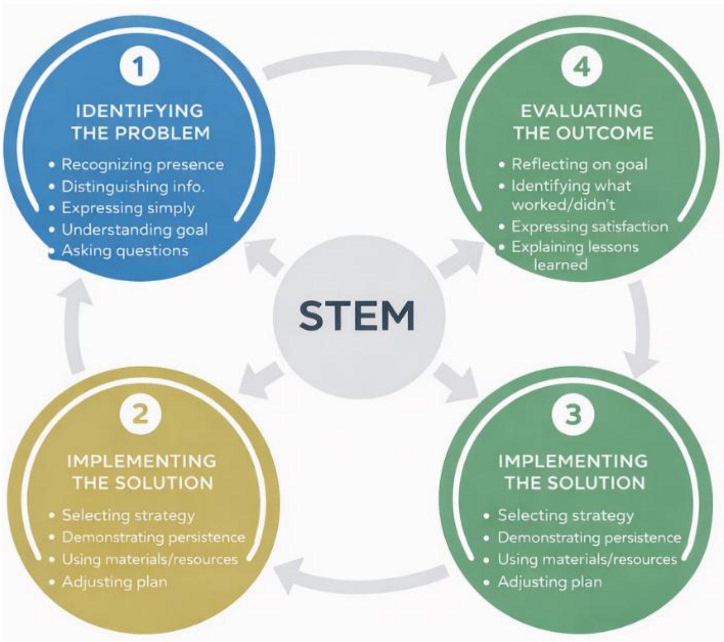
Several studies have shown that STEM-based approaches can ignite young learners' curiosity, strengthen conceptual understanding, and foster higher-order thinking even at the earliest stages of schooling (Way et al., 2022; Wan et al., 2023; Safiee et al., 2018; Lupión-Cobos et al., 2026). However, research also reveals persistent gaps in teachers' preparedness, the design of appropriate instructional units, and the availability of hands-on learning opportunities suited to the developmental characteristics of early primary students (Aydın, 2020; Halawa et al., 2024; Wieselmann et al., 2022).

In the Saudi context, there have been serious efforts in recent years to support more active and integrated learning in primary education. Many schools have started to introduce new practices that encourage inquiry and student participation. At the same time, field observations suggest that classroom practice still relies to a large extent on textbook-based teaching, especially in the early grades. Lessons are often guided step by step, with limited space for open-ended tasks or connections between subjects. Because of this, young learners may not always have enough opportunities to explore ideas freely, try different solutions, or engage with problems in a flexible way.

The problem, therefore, lies not in the lack of awareness of STEM's importance, but in the absence of structured, developmentally appropriate models that guide teachers in applying STEM principles effectively in the early grades. There is a pressing need for instructional units that are playful, integrated, and inquiry-based, enabling children to connect science, technology, engineering, and mathematics in ways that make sense to their real-world experiences. Addressing this gap is essential for nurturing young learners' problem-solving skills and equipping them with the cognitive and creative tools needed for future success. Figure 1 illustrates the conceptual relationship between STEM integration and the development of structured problem-solving skills.

Figure 1

Conceptual relationship between STEM integration and problem-solving development in early primary education



Study objectives and questions

This study aims to design and implement a STEM-based instructional unit for early primary school students (Grades 1–3) and to explore its effectiveness in developing their problem-solving skills. The research seeks to understand not only whether such a unit enhances these skills but also which specific dimensions of problem-solving are most relevant and responsive at this developmental stage.

Accordingly, the study pursues the following objectives and guiding questions:

1. To identify the problem-solving skills appropriate for primary school students (Grades 1–3) within the context of STEM-based learning.
2. To examine the effectiveness of a STEM-based instructional unit in developing these skills among young learners.

3. To analyze how the proposed STEM unit contributes to improving each dimension of problem-solving: identifying the problem, generating possible solutions, implementing the solution, and evaluating the outcome.

METHODOLOGY

Research design

The study adopted a quasi-experimental design using a one-group pretest–posttest model, which is widely used in educational research to examine the effectiveness of instructional interventions in natural classroom settings (Creswell, 2015). This design allowed for assessing the impact of the STEM-based instructional unit on students' problem-solving skills by comparing their performance before and after exposure to the learning program. A single group of participants, drawn from the first three grades of primary school, took part in the study. The instructional unit was implemented over a series of nine lessons that integrated science, technology, engineering, and mathematics concepts through hands-on and inquiry-based activities. The emphasis was on providing age-appropriate challenges that encouraged observation, experimentation, and reflective thinking.

Data were collected through an oral problem-solving skills test designed specifically for this age group. The test included four main dimensions reflecting the cognitive and practical aspects of problem-solving:

- Identifying the problem
- Generating possible solutions
- Implementing the chosen solution
- Evaluating the outcome

Pre- and post-assessments were administered under comparable conditions, and the resulting data were analyzed using appropriate statistical procedures to determine the extent of improvement in each dimension.

Participants and sampling

Out of a total population of 576 students enrolled in three public primary schools for boys in Al-Ahsa, Saudi Arabia, a sample of 46 students was selected to participate in this study. To ensure objectivity and equal opportunity, the study employed a simple random sampling technique; students' names were coded on individual slips of paper, placed in a container, and thoroughly mixed before the final participants were drawn. This sample represents a developmental continuum across the first, second, and third grades, capturing the growth of early elementary learners.

To respect the students' cognitive and linguistic stages, the problem-solving skills test was conducted orally rather than in writing. This human-centered approach allowed the children to express their reasoning naturally, ensuring that their actual problem-solving processes were captured through verbal dialogue and situational prompts without the barrier of writing proficiency.

The participants' average age was 7.6 years, a typical stage for lower-primary education. All three institutions are public schools located within the same urban zone of Al-Ahsa, which ensured a consistent socio-economic background and shared access to educational resources. Furthermore, all students followed the same national curriculum, minimizing any variables related to prior instructional exposure.

The distribution of participants was carefully balanced across the three schools to maintain representativeness, as shown in the Table 1.

Table 1

Distribution of participants and age averages across selected schools

Schools	Grade Levels	Participant Percentage	Number of Students	Average Age
School (A)	1st, 2nd, 3rd	%35	16	7.6
School (B)	1st, 2nd, 3rd	%33	15	7.6
School (C)	1st, 2nd, 3rd	33%	15	7.6
Total / Overall Average	-	%100	46	7.6Years

Note: Percentages have been rounded to the nearest whole number.

Ethical considerations

The researchers obtained official approval from the King Faisal University Research Ethics Committee (Ref: KFU-2025-ETHICS3954) to conduct this study. Adhering to established ethical standards, the study's objectives and procedures were clearly communicated to school principals, teachers, and parents. Participation was entirely voluntary, based on written informed consent provided by all parents. Additionally, the students were informed in age-appropriate language of their right to participate or withdraw at any stage without any consequence. To maintain participant privacy, all data were handled with strict confidentiality and recorded anonymously, ensuring no identifying information was linked to individual responses.

Instruments of the study

The instructional unit

Purpose of the Instructional Unit: The instructional unit was designed to provide students in the early primary grades (Grades 1–3) with meaningful opportunities to engage in integrated learning experiences grounded in STEM (Science, Technology, Engineering, and Mathematics). Its main goal was to enhance students' problem-solving abilities through hands-on, inquiry-based, and creative activities that connect classroom learning with everyday life. The unit sought to help children explore, question, and apply scientific and mathematical ideas while developing persistence, curiosity, and collaboration.

Sources of Unit Development: The development of the instructional unit was informed by both local and international studies that emphasized the importance of integrative and STEM-based approaches in early education. Foundational insights were drawn from Al-Harbi (2024) and Al-Harbi & Zaqzouq (2024), who highlighted the challenges and potential of implementing integrated STEM learning in early childhood. Almutairi (2023) provided evidence of the effectiveness of STEM-based enrichment programs in enhancing 21st-century skills, while El-Saadany et al. (2020) demonstrated the developmental benefits of STEM-oriented activities for young learners. Additionally, the design principles outlined in Capraro et al. (2013) served as a methodological foundation for structuring the unit according to international standards of project-based and inquiry-driven learning.

These sources collectively guided the adaptation of lesson ideas and learning tasks to the Saudi educational context, ensuring alignment with the national curriculum for Grades 1–3 while maintaining developmental appropriateness. Each lesson was carefully crafted to promote integrated thinking across science, mathematics, engineering design, and simple technological applications using child-friendly, low-cost materials available in local schools.

Nature and Content of the Unit: The unit comprised nine sequential lessons, each addressing a thematic problem or real-life context that encouraged students to connect learning with practice. Lessons incorporated hands-on exploration, guided inquiry, and collaborative reflection, enabling learners to make sense of STEM ideas in age-appropriate ways. Activities were designed to be playful yet purposeful, encouraging students to experiment, build, and share solutions with peers-nurturing both cognitive and socio-emotional growth. Table 2 presents an overview of the nine STEM-based lessons.

Table 2
The proposed content of the nine STEM-based lessons

Lesson	Title / Theme	Main Behavioral or Procedural Objective(s)
1	Exploring the World Around Us	Students observe natural objects, identify simple patterns, and describe their properties using basic scientific language.
2	Building Bridges	Students design and build a simple paper bridge that can hold small objects, understanding balance, weight, and structure.
3	The Floating Challenge	Students experiment with materials to determine which objects float or sink, explaining the reasons using early scientific reasoning.
4	Smart Recycling	Students classify materials according to their properties and propose creative ideas for reusing or recycling waste items.
5	Simple Machines in My World	Students explore basic machines (levers, pulleys) through hands-on play and discuss how they make work easier.
6	Coding Without Computers	Students follow visual patterns and step-by-step directions to understand sequencing and logic (early computational thinking).
7	The Power of the Sun	Students observe sunlight and experiment with its heat and shadow effects, recognizing energy as a natural resource.
8	Designing a Mini Garden	Students plan and create a small paper or real plant model, predicting what plants need to grow.
9	Solving Everyday Problems	Students collaboratively identify a classroom or home problem, propose a STEM-based solution, and present it to peers.

The oral problem-solving skills scale

To assess the development of problem-solving abilities among the participating students, an oral problem-solving scale was designed to suit the cognitive and linguistic characteristics of early primary school children. The scale was constructed in the form of situational tasks and short interactive scenarios that encouraged students to think, respond, and explain their reasoning verbally rather than through written responses. This format ensured that the tool was developmentally appropriate for children aged six to eight years.

The scale included four main dimensions, each reflecting a critical phase of the problem-solving process. Under each dimension, several sub-skills were identified to provide a detailed understanding of children's performance, as outlined below:

- *Identifying the Problem*: Recognizing the presence of a problem in a given situation; distinguishing between relevant and irrelevant information; expressing the problem verbally in simple terms; understanding the goal or desired outcome; and asking clarifying questions to ensure comprehension.
- *Generating Possible Solutions*: Suggesting multiple ways to solve the problem; Drawing on prior experiences to propose solutions; Using imagination or analogy to generate ideas; Predicting the potential outcomes of each solution; Collaborating with peers to refine ideas; and Demonstrating flexibility in thinking.
- *Implementing the Solution*: Selecting the most appropriate solution strategy; demonstrating persistence in applying the chosen approach; using available materials or resources effectively; and adjusting the plan when encountering difficulties.
- *Evaluating the Outcome*: Reflecting on whether the chosen solution achieved the goal; identifying what worked and what did not; expressing satisfaction or dissatisfaction with the result; suggesting improvements for future situations; explaining lessons learned from the experience.

The scale was validated by five experts specializing in early childhood education, psychology, and educational measurement, who confirmed the appropriateness of the content and language for the target age group. Minor adjustments were made based on their feedback to ensure clarity and developmental alignment. To verify the reliability of the scale, a pilot test was conducted with a sample of 25 students who were not included in the main study. The responses were analyzed using Cronbach's alpha coefficient, which indicated a high level of internal consistency across the four dimensions of the scale ($\alpha = 0.87$). This result confirmed that the instrument was both stable and dependable in capturing variations in children's oral problem-solving performance while ensuring that each dimension contributed meaningfully to the overall construct. To illustrate the structure and application of the oral problem-solving scale, Table 3 presents its four dimensions along with some examples of the tasks used during the assessment sessions.

Table 3

Dimensions of the oral problem-solving scale and example tasks

Dimension	Description	Example of Oral Task
1. Identifying the Problem	The ability to recognize a problem, distinguish key information, and express the challenge in one's own words.	The researchers show a picture of a broken toy and asks: "Your favorite toy stopped working. What is the problem, and what might have caused it?"
2. Generating Possible Solutions	The capacity to suggest multiple ideas or strategies, drawing on imagination, previous experiences, and reasoning.	A picture of a classroom with scattered crayons is shown. The researchers asks: "How can we organize the crayons so everyone can find their colors easily?"
3. Implementing the Solution	The ability to choose a suitable strategy and apply it practically or verbally explain the steps for solving the problem.	The researchers present a task: "You have three blocks and need to make a bridge for a toy car to cross. What will you do first?"
4. Evaluating the Outcome	Reflecting on whether the chosen solution worked, what could be improved, and what was learned from the experience.	After solving a simple construction task, the researchers ask: "Did your bridge work as you wanted? What would you change if you could build it again?"

Procedures of data collection and data analysis

The data collection process was carried out with careful attention to the comfort and engagement of the participating children. Each student was assessed individually in a quiet and familiar classroom setting to ensure focus and reduce anxiety. Every session lasted approximately 20–25 minutes, during which the researchers presented the problem-solving scenarios verbally, supported by simple illustrations and manipulatives to make the situations tangible and understandable.

The sessions followed a conversational and supportive style, allowing children to express their thoughts naturally and creatively. The researchers acted as a facilitator rather than an evaluator, using gentle prompts such as "What do you think we could do next?" or "Why did you choose that idea?" to encourage reflection without creating pressure or fear of making mistakes.

All responses were recorded immediately using structured observation sheets that captured both the accuracy of reasoning and the quality of thinking processes, such as creativity, persistence, and reflection. To ensure that children remained attentive and comfortable, the assessment was distributed across three consecutive days, giving every child the opportunity to demonstrate their problem-solving abilities in a relaxed, engaging atmosphere.

After data collection, all verbal responses were transcribed and coded according to the four main dimensions of problem-solving skills: identifying the problem, generating possible solutions, implementing the solution, and evaluating the outcome. The data were then entered into SPSS for statistical analysis. Descriptive statistics-including means, standard deviations, and percentages-were calculated to describe the participants' performance, while paired-sample t-tests were used to compare pre- and post-intervention scores.

These analyses provided a clear understanding of the extent to which the STEM-based instructional unit contributed to enhancing children's problem-solving skills and revealed how each dimension evolved throughout the learning experience.

The students' performance on the oral problem-solving scale was evaluated according to four main dimensions, each assigned a specific scoring range that reflected the number and depth of items included in the respective domain. Scores were given based on the child's level of reasoning, creativity, and accuracy of response during the interactive assessment.

Dimension 1: Identifying the Problem - Minimum score: 5, Maximum score: 15

Dimension 2: Generating Possible Solutions - Minimum score: 6, Maximum score: 18

Dimension 3: Implementing the Solution - Minimum score: 4, Maximum score: 12

Dimension 4: Evaluating the Outcome - Minimum score: 5, Maximum score: 15

Accordingly, the total scale score ranged from a minimum of 20 points to a maximum of 60 points, where higher scores indicated stronger problem-solving abilities demonstrated across the four dimensions. These scoring parameters were later used in the analysis to determine changes between pre- and post-application performance.

FINDINGS

The Findings of this study emerged from the careful observation and assessment of students' responses before and after participating in the STEM-based instructional unit. Through the nine interactive lessons, students engaged in a variety of problem-centered activities that encouraged them to think critically, explore ideas collaboratively, and apply what they learned in real-life contexts. The oral problem-solving scale provided a clear and authentic window into how young learners identify problems, generate ideas, act on their reasoning, and evaluate their outcomes. The following section presents the findings of the study in light of its four core dimensions of problem-solving. The quantitative results are supported by interpretive discussion that seeks to understand the deeper implications of the observed changes. These results not only reflect measurable growth in children's problem-solving performance but also highlight the broader educational value of integrating STEM-based learning into the early years of primary education, where curiosity and discovery lay the foundation for lifelong learning.

Results related to dimension 1: Identifying the problem

Table 4 presents the results of the pre- and post-assessment of students' performance on the first dimension of the oral problem-solving scale, Identifying the Problem. This dimension reflects the students' ability to recognize a problem, distinguish relevant information, and express it clearly in their own words.

Table 4

Pre- and post-test results for the dimension "Identifying the problem" (n = 46)

Test	Mean (M)	Standard Deviation (SD)	t-value	p-value	Effect Size (Cohen's d)
Pre-test	8.32	1.75	12.41	< .001	1.82
Post-test	12.96	1.36			

The results in Table 4 indicate a clear and statistically significant improvement in students' ability to identify problems after participating in the STEM-based instructional unit. The mean score increased from 8.32 in the pre-test to 12.96 in the post-test, suggesting that students became more skilled at observing, describing, and defining challenges in the learning situations presented to them. The obtained t-value (12.41, $p < .001$) confirms that this difference is statistically significant, while the effect size (Cohen's d = 1.82) reflects a large and meaningful practical effect, emphasizing the strong impact of the STEM-based approach on developing children's early analytical awareness.

Results related to dimension 2: Generating possible solutions

Table 5 shows the pre- and post-test results for the second dimension of the oral problem-solving scale, Generating Possible Solutions. This dimension measures students' ability to suggest multiple ideas, connect prior knowledge with new contexts, and think creatively when faced with everyday challenges.

Table 5

Pre- and post-test results for the dimension "Generating possible solutions" (n = 46)

Test	Mean (M)	Standard Deviation (SD)	t-value	p-value	Effect Size (Cohen's d)
Pre-test	9.14	1.88	9.76	< .001	1.44
Post-test	13.82	1.67			

The results reveal a statistically significant improvement in students' ability to generate and articulate diverse solutions after engaging in the STEM-based instructional unit. The mean score increased from 9.14 in the pre-test to 13.82 in the post-test, with a large effect size (Cohen's d = 1.44), confirming the educational impact of the intervention.

Results related to dimension 3: Implementing the solution

Table 6 presents the results for the third dimension of the oral problem-solving scale, Implementing the Solution, which reflects children's ability to plan and apply their ideas effectively when faced with real or simulated challenges. This dimension highlights practical reasoning, persistence, and the ability to adapt strategies during execution - key aspects of learning through the STEM approach.

Table 6

Pre- and post-test results for the dimension "Implementing the solution" (n = 46)

Test	Mean (M)	Standard Deviation (SD)	t-value	p-value	Effect Size (Cohen's d)
Pre-test	6.01	1.43	14.58	< .001	2.10
Post-test	10.14	1.12			

The findings demonstrate a remarkable and statistically significant improvement in students' ability to apply their ideas to solve problems after participating in the STEM-based instructional unit. The mean score rose from 6.01 in the pre-test to 10.14 in the post-test, marking the highest gain among all four dimensions. The large effect size (Cohen's d = 2.10) underscores the strong influence of hands-on STEM activities in enhancing children's practical problem-solving skills.

Results related to dimension 4: Evaluating the outcome

Table 7 displays the results for the fourth dimension of the oral problem-solving scale, evaluating the Outcome. This dimension assesses students' ability to reflect on their chosen solutions, judge their effectiveness, and suggest ways to improve or modify their approaches in future situations.

Table 7

Pre- and post-test results for the dimension "Evaluating the outcome" (n = 46)

Test	Mean (M)	Standard Deviation (SD)	t-value	p-value	Effect Size (Cohen's d)
Pre-test	7.84	1.69	8.23	< .001	1.22
Post-test	11.36	1.55			

The results reveal a statistically significant improvement in students' reflective and evaluative thinking after exposure to the STEM-based instructional unit. The mean score increased from 7.84 in the pre-test to 11.36 in the post-test, with an effect size of Cohen's d = 1.22, indicating a strong but comparatively lower gain than in the other dimensions. While students showed noticeable progress in evaluating the success of their solutions, the development in this domain was somewhat more gradual. This is understandable given that evaluative reasoning - which involves analyzing outcomes, identifying errors, and proposing improvements - represents a more advanced cognitive process for early primary learners.

Overall performance on the oral problem-solving scale

Table 8 presents the overall pre- and post-test results for the oral problem-solving scale, combining the four assessed dimensions into a single composite score.

Table 8

Pre- and post-test results for the total problem-solving score (n = 46)

Test	Mean (M)	Standard Deviation (SD)	t-value	p-value	Effect Size (Cohen's d)
Pre-test	31.31	3.98	16.27	< .001	2.55
Post-test	48.28	3.45			

The overall results reveal a clear improvement in students' total problem-solving performance following the implementation of the STEM-based instructional unit. The mean post-test scores indicate that the participating students demonstrated stronger, more consistent abilities across all dimensions of the scale. The statistically significant difference, supported by a large effect size, suggests that the instructional unit was effective in fostering meaningful growth in students' capacity to approach, analyze, and resolve problems through inquiry-based learning experiences.

DISCUSSIONS

The results across the four dimensions of the oral problem-solving scale show a clear pattern in how young learners deal with problems when they work within a STEM-based environment. The highest gain appeared in implementing the solution, followed by identifying the problem, then generating possible solutions, and finally evaluating the outcome. This sequence is not surprising. At this stage, children tend to act first, try things out, and only later begin to reflect on what they have done. This idea appears in earlier work on young learners, where problem-solving is described as something that grows through action, trial, and gradual awareness rather than through abstract thinking alone (Lesh et al., 2013; Sangngam, 2021; Bawaneh et al., 2026).

The strong improvement in implementation seems closely tied to the nature of the learning experience itself. The unit did not present ready answers. Instead, it placed students in situations where they had to try, adjust, and try again. During the activities, some children would say things like: "I will try this way… no, it falls… I will fix it." In one task, a student building a bridge changed the position of the blocks several times until the car could pass. This kind of behavior shows more than just understanding. It reflects persistence and a willingness to deal with failure as part of the process. Similar observations have been reported in studies where hands-on STEM tasks helped students move from passive learning to active experimentation (Safiee et al., 2018; Anwar et al., 2022). What appears here is not only skill development, but also a shift in how children approach a problem (Benschop & Husu, 2021).

The progress in identifying the problem also deserves attention. At the beginning, some students described situations in a very general way. After the unit, their responses became more focused. When shown a broken object, one child explained: "This part is not working, so it cannot move," instead of simply saying "it is broken." This shift may seem small, but it reflects a deeper change in attention and understanding. Being able to define a problem clearly is often the first real step toward solving it. Studies on early STEM learning suggest that when children work with concrete situations, their ability to notice details and make sense of them improves (Way et al., 2022; Zhou et al., 2019; Natsi & Vitsou, 2025). The same pattern appears here.

The development of generating possible solutions was present but more uneven. Some children were able to offer more than one idea and even compare them. For example, in a task about organizing materials, a student suggested: "We can put them in boxes, or maybe by colors, so we can find them faster." Others stayed with one idea and did not move beyond it. This difference may be linked to experience and exposure. Generating alternatives requires a certain level of flexibility that is still forming at this age. Research often connects this aspect of problem-solving with creative thinking and with opportunities to explore different possibilities, not just one correct answer (Santos et al., 2024; Arianto & Hanif, 2024; Muciaccia & Macchia, 2025). What the results suggest is that this ability can start to grow, but it needs more time and repeated practice.

The lowest gain appeared in evaluating the outcome, which is expected. Reflection requires stepping back from the action and thinking about what worked and what did not. Some students were able to do this in a simple way. One child said: "It worked, but it is weak. Next time I will make it stronger." Others gave short answers such as "it is good" without further explanation. This shows that evaluation is still emerging and not yet stable. Studies on early learning often point out that reflective thinking develops later and needs explicit support, especially when children are more used to doing than to explaining their thinking (Chen, 2025; Getenet, 2024; Almusharraf & Almusharraf, 2021). The results here follow the same direction.

Looking at the results as a whole, the role of the learning environment becomes clear. The unit created space for trying, failing, and trying again without pressure. Students were not limited to one path or one answer. Over time, many of them became more willing to speak, explain, and even change their ideas. This aligns with the view that problem-solving grows in environments that allow exploration and dialogue rather than strict instruction (English, 2017; Keleman et al., 2021). It also reflects what has been observed in integrated STEM settings, where learning becomes more meaningful when students are involved in doing and thinking at the same time (Wan et al., 2023; Wieselmann et al., 2022; Hiltrimartin & Pratiwi, 2025; Can & Soylu, 2025).

These outcomes can be better understood when we look at how the instructional unit was designed. Each lesson was built around a small, familiar challenge. Students were asked to build, sort, observe, or plan something related to their daily life. The tasks were simple in form, but open in response. This balance seems to have played an important role. It allowed all students to participate, while still giving space for different levels of thinking. Similar ideas appear in research on STEM unit design, where effective learning happens when activities are structured but still flexible enough to invite exploration (Halawa et al., 2024; White & Newby, 2025; Segarra-Morales & Rodríguez-Miranda, 2026; Danial et al., 2026).

Another point that appears through the results is the role of interaction. Students worked together, talked about their ideas, and listened to others. In some cases, a student changed his answer after hearing a different suggestion from a peer. This kind of exchange supports both thinking and communication. It has also been noted that collaborative work in STEM settings helps children explain their ideas and refine them over time (Goodnough et al., 2014; Ismail & Shahpo, 2025).

At the same time, the results reflect something about the classroom context. When students are used to following fixed steps, even small changes in teaching can lead to noticeable differences. Giving them the chance to explore, even in simple tasks, seems to open new ways of thinking. This may explain why the strongest gains appeared in action-based skills, while reflective skills developed more slowly. It suggests that moving from structured instruction to more open learning does not happen all at once, but step by step. In general, the findings show that young learners are capable of engaging in meaningful problem-solving when they are given the opportunity. They may not fully explain or evaluate their thinking yet, but they can act, test, and improve. With continued exposure to similar learning experiences, these early abilities can grow into more complex forms of reasoning over time.

EDUCATIONAL IMPLICATIONS FOR THE STUDY

The findings of this study carry meaningful implications for early primary education and for how teachers, curriculum designers, and policymakers approach the integration of STEM-based learning in the first years of schooling. The study demonstrated that even young children, when guided through structured yet playful STEM experiences, can engage in genuine problem-solving, make reasoned decisions, and begin to think reflectively about their actions.

For teachers, this suggests the need to reimagine classroom practices as spaces for inquiry and exploration rather than mere knowledge delivery. Lessons built on everyday problems, simple experiments, and collaborative projects can make abstract concepts tangible and relevant. When teachers allow room for trial, error, and reflection, they nurture not only cognitive growth but also persistence, curiosity, and confidence in learning. For curriculum developers, the results highlight the importance of designing units that integrate subjects meaningfully rather than treating science, mathematics, and technology as isolated topics. A cohesive STEM framework in the early grades can help children perceive knowledge as interconnected and applicable to real-world contexts. At the policy level, the findings call for professional development programs that equip early-grade teachers with the pedagogical and practical tools to implement STEM-based instruction effectively. Investment in training, materials, and classroom resources will ensure that children experience learning that is engaging, exploratory, and developmentally appropriate.

This study reinforces the idea that STEM is not beyond the reach of young learners-when presented through hands-on, age-appropriate, and integrative methods, it becomes a powerful pathway for cultivating problem-solvers who are curious, confident, and prepared for the challenges of the future.

CONCLUSION

This study set out to explore how a STEM-based instructional unit could enhance problem-solving skills among primary school students. The findings revealed that when children engage in guided exploration through integrated and hands-on learning experiences, their ability to recognize problems, generate solutions, apply strategies, and evaluate outcomes improves noticeably. The unit's nine lessons provided opportunities for students to connect science, mathematics, engineering, and technology in meaningful ways, transforming classroom learning into an active process of discovery and reflection. The progression in students' performance across all four dimensions of problem-solving shows that structured STEM activities can nurture both analytical and creative thinking from an early age. Children not only learned how to find answers but also developed confidence in questioning, experimenting, and refining their ideas. These results highlight the importance of introducing STEM principles early in schooling, as this stage lays the foundation for habits of inquiry, perseverance, and adaptability that will support lifelong learning. The study also suggests that when teachers are empowered to design lessons that bridge disciplines and connect learning to real-life contexts, students begin to view challenges as opportunities for exploration rather than obstacles. The research affirms that STEM education, when thoughtfully adapted to the developmental level of young learners is not just about teaching science or technology. It is about cultivating curiosity, resilience, and the joy of discovery - qualities that form the heart of meaningful education.

LIMITATIONS OF THE STUDY

While the study provided valuable insights into the impact of STEM-based instruction on young learners' problem-solving skills, several limitations should be acknowledged. First, the sample size was relatively small and limited to three public schools in a single city, which may restrict the generalizability of the findings to other educational contexts or regions. Second, the study employed a quasi-experimental design without a control group, which limits the ability to attribute observed improvements solely to the intervention. Another limitation lies in the duration of the intervention. The instructional unit consisted of nine lessons implemented over a short period, which may not fully capture the long-term effects of sustained STEM-based learning on children's cognitive and behavioral development. Additionally, the use of oral problem-solving assessments, though appropriate for the students' developmental level, relied partly on qualitative judgments and teacher observations, which could introduce subjectivity despite efforts to ensure reliability. The study did not examine external factors such as teacher experience, classroom environment, or parental support, all of which could influence students' engagement and performance. Recognizing these limitations provides direction for future research to refine the design, expand the sample, and explore broader contextual variables that shape the effectiveness of STEM integration in early education.

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Ethical statement

This study was approved by the Research Ethics Committee at King Faisal University (Ref: KFU-2025-ETHICS3954). Participation was voluntary, with written informed consent obtained from parents. Students were informed of their right to withdraw at any time. All data were collected anonymously and handled with strict confidentiality.

Competing interests

The authors declare that they have no competing interests.

Author contributions

Abdelrahim Fathy Ismail conceptualized the study, designed the research methodology, supervised the implementation, conducted data analysis, and drafted the manuscript. Khaled Ahmad Obeidat contributed to the study design, data interpretation, and manuscript revision. Afaf Abdelah Othman assisted in data collection, instrument development, and initial data analysis. Alaaeldin Ahmed Hamid contributed to data collection, literature review, and manuscript editing. All authors reviewed and approved the final version of the manuscript.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

AI disclosure

The authors acknowledge the use of ChatGPT as an AI-assisted language tool in the preparation of this manuscript. The tool was used solely for linguistic editing, improving clarity, refining academic phrasing, and organizing certain sections of the text. As non-native English speakers, the authors used the tool exclusively to enhance the quality and readability of the language. ChatGPT was not used to generate original data, analyze research results, create figures or images, or produce substantive intellectual content without critical review and supervision. All authors take full responsibility for the integrity, accuracy, originality, and final content of the manuscript.

Biographical sketch

Dr. Abdelrahim Fathy Ismail is a Professor of Curriculum and Instruction at the College of Education, King Faisal University, Saudi Arabia. His work centers on teaching and learning, with a particular interest in effective instructional strategies, early childhood education, and the integration of artificial intelligence in education. He has contributed to a number of research projects and published in international peer-reviewed journals, aiming to support meaningful learning experiences and improve educational practices across diverse contexts.

Dr. Khaled Ahmad Obeidat is a faculty member at the College of Educational Sciences, Ajloun National University, Jordan. He holds a PhD in Special Education. His academic work focuses on supporting learners with diverse needs, particularly in the areas of learning disabilities and intellectual disabilities. His research interests include assessment and intervention strategies, inclusive education, and improving educational outcomes for students with special needs. He has contributed to several research projects and published in peer-reviewed journals, aiming to enhance teaching practices and promote equitable learning opportunities.

Dr. Afaf Abdelah Othman is a Professor of Educational Psychology at the College of Education, Najran University, Saudi Arabia. Her work focuses on teaching and learning, with a particular focus on effective teaching strategies, quality in education, and the integration of AI in education. She has contributed to a number of research projects and published in international peer-reviewed journals with the aim of supporting meaningful learning experiences and improving educational practices across diverse contexts.

Dr. Alaaedin Ahmed Hamid is an Associate Professor of Art Education at King Faisal University. He specializes in metalwork and artistic crafts, with a strong focus on integrating traditional and contemporary techniques in art education. He earned his PhD from Ain Shams University and has extensive experience in teaching, research, and supervising graduate studies. Dr. Hamid has published several academic papers and actively contributes to workshops, exhibitions, and community engagement initiatives, promoting creativity, sustainability, and innovation in visual arts education.

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