EUROPEAN JOURNAL OF STEM EDUCATION

European Journal of STEM Education,
2026, 11(1), 3
eISSN: 2468-4368

lectito

Research paper

Exploring a STEM-Integrated Instructional Approach and Its Preliminary Contextual Assessments of Problem-Solving and Motivation in Oman

Marwa Al-Hinai [1], Mohamed A. Shahat [2*], Ehab Omara [2], Mahmoud M. Emam [2], Sameh S. Ismail [2], Nabil Alhabsi [1], Khoula Alhosni [2], Mohammed Al-Amri [2], Amur Al-Yahmedi [2], Yasser M. Fawzy [2], Sulaiman M. Al-Balushi [2]

[1] *Ministry of Education,* OMAN
[2] *Sultan Qaboos University,* OMAN

*__Corresponding Author:__ m.shahat@squ.edu.om

Citation: Al-Hinai, M., Shahat, M. A., Omara, E., Emam, M. M, Ismail, S.S., Alhabsi, N., Alhosni, K., Al-Amri, M., Al-Yahmedi, A., Fawzy, Y. M., Al-Balushi, S. M. (2026). Exploring a STEM-integrated instructional approach and its preliminary contextual assessments of problem-solving and motivation in Oman. *European Journal of STEM Education, 11*(1), 3. https://doi.org/10.20897/ejsteme/17783

Published: January 25, 2026

ABSTRACT

This study investigates how using the Engineering Design Process (EDP) to deliver culturally contextualized STEM education can enhance problem-solving skills and motivation among fourth-grade students in Oman, while also examining whether these outcomes differ by gender. Using a quasi-experimental design, 118 students participated in either a STEM-based instructional intervention or a traditional science curriculum. The intervention featured hands-on, inquiry-driven, and locally meaningful tasks that directly reflect students' real environmental and cultural experiences in Oman. These included constructing weather-resistant animal shelters, designing floating paper boats, creating chocolate molds suited for warm climates, and developing low-cost oil-spill cleanup solutions using readily available local materials. These contextually grounded challenges, highlighted as a central strength of the study, demonstrate how the EDP can authentically align global STEM competencies with regional realities. The findings revealed preliminary evidence of improvements in the problem-solving dimensions of problem identification, planning, and production, as well as in motivational factors such as responsibility and engagement. However, no significant gains were observed in self-efficacy or peer collaboration, indicating areas for future instructional enhancement. This study underscores the value of culturally responsive, practice-based STEM pedagogy and provides initial insights into the use of contextualized, performance-based assessments to explore students' cognitive and motivational development in primary STEM education.

Keywords: STEM, problem solving, motivation, primary stage, Oman

In light of Oman's growing focus on improving educational outcomes, particularly in response to low student performance in international assessments such as TIMSS, there has been an increasing emphasis on the integration of Science, Technology, Engineering, and Mathematics (STEM) education (Ambusaidi et al., 2022; Shahat et al, 2022 a; Shahat & Al-Balushi, 2023). This strategic focus is part of Oman's Vision 2040, which emphasizes fostering innovation and technological advancement across various sectors, including education. STEM education is widely recognized as a means of equipping students with interdisciplinary skills necessary to address the complexities of the 21st century. These skills enable students to engage with real-world challenges, enhance critical thinking, and contribute to the global knowledge economy (Hafni et al., 2020; Razali et al., 2020; Zhai et al., 2023).

While the global significance of STEM education is well-documented, limited research has focused on its implementation in Middle Eastern contexts, particularly in Oman. Studies have predominantly explored STEM education in Western settings, leaving gaps in understanding how cultural and environmental factors influence its effectiveness in different regions (Shahat et al., 2022a). Oman's unique geographic and cultural conditions, such as high temperatures, frequent sandstorms, and the need for sustainable solutions in arid climates, present challenges and opportunities for contextualizing STEM education. These factors show us the importance of designing culturally relevant instructional approaches that align with students' lived realities while fostering innovation and problem-solving capabilities (Grewe, 2025; Shahat & Al-Balushi, 2023).

A particularly novel aspect of this study is the use of the Engineering Design Process (EDP) to culturally relevant problem contexts, without modifying the process itself, to emphasize iterative problem-solving through real-world challenges. The EDP includes key stages such as problem identification, planning, prototype development, testing, and refinement, closely aligning with the multi-step cognitive processes evaluated in this study (Cross, 2004; Museum of Science, Boston, 2016). By adapting this globally recognized model to the Omani context, the study addresses regional educational challenges and contributes to the broader discourse on the adaptability of STEM frameworks in diverse cultural settings (Pontes & Albuquerque, 2025).

In this paper, the term 'STEM education' refers to an integrated pedagogical approach that combines the disciplines of Science, Technology, Engineering, and Mathematics into cohesive, inquiry-based learning experiences. Unlike definitions that treat STEM as a collection of separate curricula, this study emphasizes its interdisciplinary nature, focusing on how real-world applications can be used to integrate all four subjects to encourage creativity, teamwork, and critical thinking (Museum of Science, Boston, 2016; Khalil et al., 2023).

By examining the impact of an integrated STEM-based instructional unit on the problem-solving skills and motivation of fourth-grade students, this research aligns with Oman's strategic education goals. Moreover, it explores whether male and female students benefit equally from culturally contextualized STEM learning, given persistent concerns about gender equity in STEM education globally. The instruction is designed around challenges that have been adapted to local conditions; for example, an egg drop challenge was adapted to address local environmental conditions, and a stray animal shelter construction challenge was modified to incorporate concepts related to sustainability. These modifications aim to enhance engagement, foster critical thinking, and equip students with the skills necessary to tackle regional and global challenges (Ahmed, 2016; Idris et al., 2023; Shahat et al., 2024 a, b). By embedding culturally relevant themes - such as local environmental concerns and community care roles - the instruction resonates with students' lived experiences and societal values in Oman.

Theoretical background

Problem-solving skills and the role of STEM education

STEM education plays a vital role in developing students' problem-solving skills, critical thinking, and creativity (Soros et al., 2018). In this study, "problem solving" refers to a structured cognitive process involving the identification, analysis, and resolution of challenges through interdisciplinary STEM principles (Delahunty et al., 2020). While problem-solving is traditionally associated with mathematics and engineering, the present study adopts a broader perspective that integrates knowledge from multiple STEM domains. For instance, designing a device to protect an egg from breaking requires students to draw on concepts from mathematics, engineering, material science, and technology. This interdisciplinary framing highlights the potential of STEM education to foster applied problem-solving that extends beyond single-discipline boundaries (Museum of Science, Boston, 2016; NASA, 2012).

The current intervention was explicitly informed by prior research that demonstrates how specific STEM-based learning experiences aid problem-solving development. For instance, Ahmed (2016) used STEM units that featured hands-on tasks, including tower building and vehicle design, in primary classrooms and found significant gains in students' problem-solving performance. These same principles guided the inclusion of tasks such as the "egg drop challenge" in the current study. Similarly, Darwish (2024) and Chowdhury and Shil (2021) emphasized that design-based tasks contribute to engineering thinking and spatial ability—two cognitive processes targeted through the project-based activities used in this study.

Although Forbes et al. (2021) investigated the use of 3D printing to support experimentation and design iteration, the current intervention achieved similar outcomes through the use of low-tech materials in authentic, context-based challenges. The essence of their findings - namely, that iterative design tasks enhance higher-order thinking - shaped the design of the activities used in this study that required students to develop, test, and refine prototypes. These parallels demonstrate how previous STEM interventions inform the pedagogical structure and task design of the current study, even though the technological tools may differ.

Problem-solving, as framed here, involves iterative processes: recognizing a problem, planning a solution, implementing a design, testing outcomes, and refining approaches (Khalil et al., 2023). Each step is aligned with the Engineering Design Process (EDP), which served as the backbone of the instructional sequence. Tasks such as a shelter construction for stray animals and an egg protection challenge were deliberately selected to simulate authentic problems relevant to students' lived experiences, increased the perceived value of problem-solving activities and promoting deeper engagement (Ismail & Shahpo, 2025; Zhai et al., 2023).

Despite robust pedagogical foundations, studies on performance-based problem-solving assessments have highlighted the complexities of designing and scoring open-ended tasks (e.g., Delahunty et al., 2020). Such assessments typically require analytic rubrics, multiple raters, and evidence of reliability and validity beyond simple internal consistency. These considerations informed the structure of the instruments used in this study and the decision to treat them as preliminary prototypes requiring future psychometric refinement.

Motivation towards science and the role of STEM

This study is informed by Ryan and Deci's (2000) self-determination theory (SDT), which emphasizes the desire in students to engage in learning for its own sake. STEM education, particularly when implemented through inquiry-based and hands-on approaches, is well-suited to foster this intrinsic motivation as it provides autonomy, relevance, and opportunities for the meaningful application of knowledge.

The intervention in this study was also directly shaped by research highlighting how real-world, project-based tasks contribute to increased student motivation. For example, Tan et al. (2021) found that integrating scientific inquiry with authentic tasks boosted both motivation and learning outcomes.

Unlike some studies that investigated high-tech tools such as 3D printing or VR (e.g., Forbes et al., 2021; Yang & Baldwin, 2020), the current intervention relied on low-tech, accessible materials. However, the theoretical underpinning is similar in that students need tangible, design-based tasks that promote exploration, ownership, and iterative refinement. These elements - found in both the literature and the present intervention - were intentionally used to target motivational outcomes such as engagement and responsibility.

Idris et al. (2023) and Bouzghia (2024) stress that when students engage in dynamic, inquiry-driven environments, they experience a stronger emotional connection to science learning. This principle informed the structure of the intervention used here, which allowed students to work collaboratively on meaningful problems with open-ended solutions. Similarly, Alsaeidan et al. (2023) and Mohammed and Al-Harbi (2024) provide evidence that project-based science education improves achievement motivation by empowering students to take ownership of their learning—a goal reflected in the design of tasks that required planning, teamwork, and sustained problem-solving.

The present study's focus on motivational components, particularly responsibility and engagement, was informed by prior research showing how task authenticity, cultural relevance, and opportunities for student agency shape motivational responses in STEM learning. Specifically, studies such as Tan et al. (2021), Idris et al. (2023), and Bouzghia (2024) demonstrate that when students engage in authentic, culturally meaningful, and inquiry-driven STEM tasks, they display higher levels of responsibility, sustained engagement, and a stronger emotional connection to learning. Rather than relying on generic claims about how hands-on instruction is motivating for students - that is, broad assertions commonly noted in the literature that simply state that practical or activity-based lessons increase motivation without specifying the mechanisms, contextual factors, or types of tasks involved -the intervention and the selection of items in the motivation scale were deliberately grounded in evidence-based research demonstrating how contextualized, authentic STEM challenges enhance responsibility, engagement, and emotional connection to learning (e.g., Idris et al., 2023).

While task authenticity was emphasized earlier as an instructional strength, performance-based assessments in STEM and engineering education also require attention to assessment authenticity, alongside construct representation and scoring reliability, to ensure that the tasks validly capture the targeted cognitive processes (Pellegrino et al., 2016). Existing studies, such as Delahunty et al. (2020), highlight that open-ended, design-based tasks often yield only moderate reliability due to the complexity involved in scoring iterative problem-solving processes. This literature provides important context for interpreting the preliminary nature of the PST used in the present study and underscores the need for continued refinement and validation in future work.

To unify the theoretical foundations guiding this study, the EDP is presented as the pedagogical structure through which elements of SDT and problem-solving cognition intersect. It is important to clarify, however, that only selected components of this framework were empirically examined. The motivational outcomes assessed - responsibility, engagement, self-efficacy, and collaboration - reflect practical dimensions aligned with aspects of SDT, while other constructs discussed in the theoretical narrative remain conceptual and were not directly tested. Likewise, although the EDP provided the structural backbone of the intervention, the proposed links between individual EDP phases and specific cognitive or motivational processes were not empirically validated. These relationships are therefore presented as theoretically informed rather than empirically confirmed, and the integrated framework should be understood as a guiding model rather than a set of causal pathways evaluated in this study.

Within this conceptual framing, the iterative phases of the EDP offer a pedagogically meaningful structure with stages that link to the three basic psychological needs during problem-solving activities outlined in SDT, that is, autonomy, competence, and relatedness (Ryan & Deci, 2000). This structure supports these needs by sequencing learning in ways that naturally create opportunities for choice, mastery, and social connection, consistent with research showing that iterative, inquiry-driven STEM tasks enhance motivational engagement (Tan et al., 2021). The problem-identification and ideation phases nurture autonomy by allowing students to select approaches and propose alternative solutions, aligning with findings that student agency contributes to stronger motivational responses in STEM learning (Shahidullah & Hossain, 2022; Idris et al., 2023). The planning, prototyping, and testing phases strengthen competence by engaging learners in applying scientific principles, evaluating evidence, and refining designs—processes shown to build mastery and higher-order thinking in design-based tasks (Forbes et al., 2021). Finally, the evaluation and communication phase fosters relatedness through peer dialogue and collaborative reflection, echoing research highlighting the role of structured collaboration in sustaining engagement and social connectedness in STEM contexts (Alsaeidan et al., 2023)

Gender considerations in STEM education

An examination of Gender differences in STEM education warrants inclusion here, given the study's focus on whether male and female students respond differently to the intervention. Numerous studies suggest that gender can influence students' attitudes, motivation, and performance in STEM-related learning environments. For instance, Smith et al. (2022a) noted that in STEM disciplines, female students often report lower self-efficacy, particularly in engineering-focused tasks, due to sociocultural stereotypes and reduced exposure to design-based learning. However, the study also found that when females engage in collaborative, hands-on STEM tasks with real-world relevance, these self-efficacy gaps tend to narrow. This suggests that interventions grounded in inquiry and design - such as the one implemented in the current study - may help to create more equitable learning experiences across genders. Similarly, Zainil et al. (2023) and Forbes et al. (2021) emphasized that project-based and contextualized STEM learning can mitigate gender-based disparities in interest and engagement. Their findings support the hypothesis that both genders can benefit equally from interventions that provide autonomy, cultural relevance, and teamwork opportunities.

The current study's use of problem-solving challenges rooted in students' daily lives was designed to offer inclusive entry points for all learners. By analyzing gender differences, the study seeks to understand whether such culturally adapted STEM experiences are equally effective for male and female students - a question of both practical and theoretical importance in the development of equitable STEM education models.

The STEM educational model

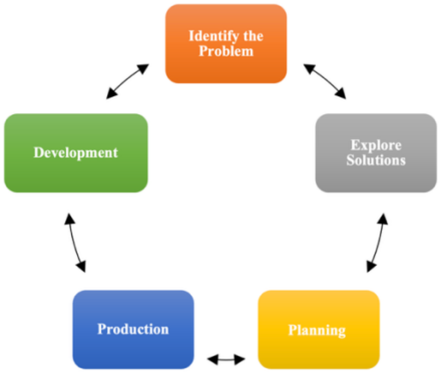
At the heart of this study is the EDP - a widely used STEM instructional model that provides a structured, cyclical approach to problem-solving. The EDP includes key phases: identifying a problem, exploring possible solutions, planning and creating prototypes, testing, and refining (NASA, 2012; Schön, 2006). This approach supports the development of essential 21st-century competencies, including critical thinking, collaboration, and adaptability (Cross, 2004; Shahat & Al-Balushi, 2023, Shahat, Al Amri, 2023). Within the scope of this study, the EDP was not only used as a procedural framework for design-based learning but also as a pedagogical mechanism that operationalizes SDT. Its iterative phases were intentionally structured to foster autonomy, competence, and relatedness, core motivational needs that underpin students' engagement in problem-solving cognition (Alazri & Shahat, 2025; Shahat & Al-Balushi, 2025). **Figure 1** illustrates the EDP model used in this study.

It is important to clarify that the EDP's sequence of stages - problem identification, planning, prototyping, testing, and redesign - remained unchanged. What was localized were the challenges presented to students, not the structure of the framework itself. This distinction underscores the strength of the EDP as a globally applicable model that can flexibly accommodate a variety of problem contexts without modification to its core pedagogical logic.

This study contributes to the literature on culturally responsive STEM instruction by demonstrating how standard frameworks such as the EDP can be implemented meaningfully through regionally adapted learning scenarios. In doing so, it aligns with research emphasizing the importance of contextual relevance in STEM education for improving student motivation, engagement, and applied problem-solving skills (Shahat et al., 2024a; Shahat et al., 2024b; Zhai et al., 2023). The combination of culturally relevant and iterative challenges structured using the EDP provides a promising direction for designing effective STEM curricula that are both globally grounded and locally meaningful.

Figure 1

The engineering design model



Aims and research questions

This study evaluates the impact of a STEM-based instructional unit that integrates Science, Technology, Engineering, and Mathematics into a cohesive, inquiry-based learning framework designed to enhance problem-solving skills and motivation among fourth-grade students in Oman. For this study, STEM education refers to an integrated pedagogical approach that applies interdisciplinary knowledge to real-world challenges. The study specifically investigates how engaging, hands-on applications of scientific principles, adapted to Oman's cultural and educational context, influence student motivation and problem-solving abilities. Additionally, it examines gender differences to understand how male and female students respond to STEM-based instruction.

Globally, STEM education has demonstrated its effectiveness in fostering critical thinking and engagement, yet its integration into Oman's education system remains limited.

The research questions guiding the study are (RQs):

- RQ1: How does experiencing a culturally and contextually adapted STEM-based instructional unit impact the problem-solving skills of fourth-grade students in Oman?
- RQ2: How does a STEM unit contextualized for Oman's educational and socio-environmental needs affect students' motivation and enthusiasm for learning science?
- RQ3: How do male and female students differ in their response to the STEM instructional unit in terms of problem-solving skills and motivation?

METHODOLOGY

Design

This study employed a quasi-experimental research design to evaluate the impact of a STEM-based instructional unit on fourth-grade students' problem-solving skills and motivation in Oman. Quasi-experimental designs of this type are widely used in school-based research where educational datasets frequently involve nested structures - students within classes or schools - which can influence variance and statistical inference (Field, 2009). While the present sample size did not permit multilevel modeling, these considerations guided the interpretation of the results and the choice of analytic strategies (Field, 2009). The intervention incorporated inquiry-driven, hands-on activities contextualized to local cultural and environmental conditions, while the control group followed a traditional, textbook-based science curriculum. The study used pre- and post-tests spaced six weeks apart to assess the impact of the intervention.

Participants

A total of 118 fourth-grade students participated in the study, with 56 students in the treatment group and 59 in the control group. Participants were selected from four public mixed-gender elementary schools in Oman, ensuring diversity in gender, socioeconomic background, and academic performance. Assignment to experimental conditions occurred randomly at the classroom level. One intact class was selected from each of the four participating public schools, with two classes assigned to the control group and two to the experimental group. Ethical approval (Approval No. 2823858754) was obtained from the Ministry of Education in Oman. Prior to participation, written informed consent was obtained from the students' parents or legal guardians. In addition, consent was obtained from all student participants. The purpose and procedures of the study were explained to them in age-appropriate language, and it was emphasized that participation was voluntary and that they could withdraw at any time without penalty. These procedures ensured compliance with ethical research standards (Shahat et al., 2024 b, c).

In addition to formal ethical compliance, the research team made a concerted effort to self-reflect on possible sources of bias in carrying out this research. The researchers positionality must be acknowledged to ensure transparency and take account of how their beliefs and experiences potentially impact the study. The lead researchers, educators, and science education specialists, familiar with the Omani school system, occupied an insider–outsider position, sharing cultural and linguistic understanding with participants while maintaining professional distance to preserve objectivity. Reflexive discussions were conducted during data interpretation to minimize potential bias, acknowledge contextual influences, and enhance the trustworthiness of the findings within the cultural and linguistic specificity of Oman. Particular attention was given to how gender norms, social class backgrounds, and ethnic diversity within Omani society might shape participants' educational experiences and responses. These sociocultural values were critically reflected upon throughout the research process to ensure that interpretations remained sensitive to underlying power dynamics and did not privilege any particular group's perspective (Tewolde, 2024).

Intervention

The experimental group received a structured STEM-based instructional unit designed to develop students' problem-solving abilities and motivation through hands-on, inquiry-oriented learning. The unit consisted of six culturally grounded lessons tailored to real-world challenges in Oman. Each lesson followed the EDP, comprising five iterative phases: problem identification, investigation, planning, production and testing, and improvement. These tasks integrated concepts from the four STEM domains and emphasized teamwork, iteration, and reflective thinking.

To minimize teacher-related confounds, the participating schools identified four teachers with comparable qualifications and teaching experience - two assigned to the experimental classes and two to the control classes. Teachers did not self-select into conditions; instead, allocations were determined by school administration based on existing class assignments to avoid disrupting the normal timetable. To support consistency in instructional delivery, the teachers responsible for the experimental classes received a half-day training session and a detailed orientation on the STEM–EDP unit, while the control-group teachers continued using the standard science curriculum and common teaching. All teachers adhered to the same pacing guides and assessment timelines throughout the study. Furthermore, to strengthen comparability of instruction and further reduce potential teacher or class effects, a standardized instructional observation sheet was employed (Clausen, 2002), which was translated into Arabic and back translated to ensure validity (Shahat et al., 2017). All lessons were fully documented in the teacher's guide and supplementary materials to ensure transparency and reproducibility. All instructional materials - including lesson scenarios, teacher guides, and assessment rubrics - are provided in the supplementary materials to support replication. While some aspects of classroom dialogue and teacher prompts were context-dependent and not verbatim recorded, the consistent use of the validated Engineering Design Process framework ensures methodological rigor and pedagogical reproducibility.

The six instructional challenges implemented throughout the unit are summarized in **Table 1**, each representing a distinct STEM task contextualized within the local environment. These included designing a skeleton model, constructing an animal shelter, creating a pen holder from recycled materials, building a floating paper boat, developing a cost-effective oil spill cleanup solution, and formulating a chocolate mold that retains its shape in warm temperatures.

Table 1

STEM challenges implemented in the intervention

Challenge Title	Real-World Context
1. Designing a Skeleton Model	Explore skeletal systems by building a model of a dinosaur using basic materials
2. Building a Simple Animal Shelter	Design a stable, weather-resistant shelter for birds nesting in desert environments
3. Creating a Pen Holder (Recycling)	Repurpose plastic waste into functional objects to reinforce environmental responsibility
4. Constructing a Floating Paper Boat	Build a floating, water-resistant boat and explore design balance and buoyancy
5. Removing an Oil Spill (on a Budget)	Develop a low-cost, eco-friendly solution to clean up oil spills
6. Designing a Chocolate Mold	Create a chocolate mold that maintains shape in warm Omani weather

One illustrative lesson, building a simple animal shelter, is detailed in **Table 2**. In this challenge, students were tasked with designing and constructing a stable, weather-resistant bird shelter using low-cost, locally available materials. The lesson addressed multiple learning objectives, including application of the EDP, understanding environmental adaptation, and using tools and measurements effectively. Students worked collaboratively in small teams, assuming rotating roles such as planner, builder, and materials manager to sketch, construct, test, and refine their models.

Table 2

stem lesson example: Building a simple animal shelter

Component	Details
Lesson Scenario	Students design a bird shelter for use in a desert oasis that is stable, wind-resistant, and dry inside.
Learning Objectives	Apply the EDP, understand environmental adaptation, and use tools and measurements effectively.
STEM Integration	Science (habitat, weather), Math (measurement, dimensions), Engineering (structural design), Technology (tool usage).
Materials Provided	Paper bags, felt, sticks, moss, string, scissors, modeling clay, watering can, electric fan.
Evaluation Criteria	Stability, wind resistance, water resistance, and proper enclosure with a single entrance.

The Engineering Design Process was fully embedded in this task, as outlined in **Table 3**. Students began by identifying the challenge requirements and constraints. They then investigated appropriate shelter designs, selected suitable materials, and produced prototypes. These were tested under simulated wind (using an electric fan) and rain (using a watering can) conditions. Based on test results, teams reflected and refined their designs to improve structure and function.

Table 3

Engineering design process (EDP) walkthrough for the animal shelter challenge

EDP Stage	Implementation in the Lesson
1. Problem Identification	Students discuss shelter design criteria and environmental challenges.
2. Investigation	Teams brainstorm solutions, research materials, and explore structural principles.
3. Planning	Students sketch designs, assign team roles, and prepare a material list.
4. Production & Testing	Teams construct prototypes and test them using wind and rain simulations.
5. Improvement	Students revise their shelters based on test outcomes and reflect on design effectiveness.

The shelter challenge exemplifies effective STEM pedagogy. It combines disciplinary content with real-world application, engaging students in tangible problem-solving that enhances understanding and motivation. The testing phase introduced authentic constraints and provided opportunities for immediate feedback and revision, reinforcing key concepts of the EDP.

Beyond content mastery, the lesson cultivated essential 21st-century skills, including collaboration, communication, creativity, and adaptability. Structured team roles ensured equitable participation, while the teacher's facilitative role supported student inquiry, exploration, and reflective learning.

In contrast, the control group followed a traditional, textbook-driven science curriculum. Instruction was teacher-centered, emphasizing factual recall and summative assessment, with limited opportunities for collaboration, experimentation, or design iteration. Technology use in the control group was largely passive (e.g., PowerPoint presentations), and formative feedback was minimal.

Instruments

Two instruments were developed to evaluate the effectiveness of the STEM-based instructional intervention: the Problem-Solving Test (PST) and the Motivation Scale (MS). These tools were designed to assess the cognitive and motivational impact of a culturally contextualized STEM unit on fourth-grade students in Oman. The development of both instruments followed a rigorous process, including expert reviews, pilot testing, and reliability analysis, to ensure content relevance and measurement quality.

Problem-solving test

The Problem-Solving Test was designed by the authors to assess five dimensions of students' STEM-related problem-solving ability: problem identification, finding a solution, planning, production, and development. The test consisted of three open-ended performance tasks designed to elicit evidence of students' problem-solving processes through real-world, age-appropriate challenges. These tasks included: (1) the Egg Drop Challenge, adapted to simulate Oman's extreme heat conditions by requiring students to design a protective device using only locally available and biodegradable materials (e.g., palm leaves, cotton, cardboard, and twine) to prevent a raw egg from breaking when dropped from increasing heights (4 m, 6 m, and 8 m). The device had to remain intact after exposure to a heated surface (simulated using sun lamps or black trays placed outdoors) for at least 10 minutes to mimic local temperature conditions., (2) a Bridge Design Challenge requiring students to span a 30 cm gap using basic materials, and (3) a Water Filter Construction task that involved building a functional filter from everyday items. Each task was scored using a 5-point analytic rubric across the five problem-solving dimensions, resulting in 25 points per task and a maximum total score of 75.

The scoring rubrics were adapted from engineering design assessment frameworks (e.g., Hsu et al., 2011) and reviewed by seven STEM experts for validity and appropriateness. Each rubric included clear descriptors for scoring levels from 1 (limited) to 5 (excellent) in each dimension. For example, the "Problem Identification" rubric for the bridge challenge ranged from vague or incorrect problem descriptions (score = 1) to clearly articulated goals with relevant constraints and requirements (score = 5). The tasks and rubrics were developed to reflect the iterative nature of the Engineering Design Process and were aligned with the skills targeted by the instructional intervention.

The test was piloted with 30 fourth-grade students from schools not involved in the study. Data from the pilot informed the refinement of task instructions, visual scaffolds, and rubric clarity. The PST takes about 43 minutes for students to complete. The internal consistency of the PST, measured using Cronbach's alpha, was 0.66. While this value is below the widely accepted threshold of 0.70, it is considered a provisional indicator of moderate reliability in exploratory studies involving open-ended, performance-based assessments for primary school students (Delahunty et al., 2020; Abdullah et al., 2024). While still at an early stage of development, this instrument represents a preliminary, context-specific attempt to assess performance-based STEM problem solving among primary-level students in Oman. It was designed primarily to accompany and evaluate a culturally grounded intervention. To our knowledge, no fully validated Arabic-language tools currently exist that assess problem solving within the Engineering Design Process framework, particularly in authentic, hands-on contexts. The decision to develop this measure was therefore driven by the lack of culturally appropriate and developmentally suitable assessments capable of capturing the iterative and applied nature of engineering design tasks that were central to the intervention.

Given the absence of existing Arabic-language performance-based assessments aligned with the Engineering Design Process, the PST was developed as an exploratory tool informed by psychometric research that values clear construct definitions, iterative rubric refinement, and evidence of scoring reliability in performance-based assessments (Hsu et al., 2011; Pellegrino et al., 2016). Most existing instruments rely on multiple-choice formats or broad cognitive indicators that do not reflect the practical, design-oriented tasks targeted in this study. As a result, the present PST should be viewed as a pilot prototype aligned with the initial stage of the MEASURE framework for instrument development (Kalkbrenner, 2021).

The development of performance-based assessments also requires careful adherence to construct representation, scoring procedures, and systematic validation (Pellegrino et al., 2016). Consistent with these principles, the tasks and analytic rubrics used in this study were reviewed by domain experts, piloted with a separate group of students, and scored by trained raters to promote scoring consistency and procedural rigor. However, these steps represent only the early phase of a broader validation program. The PST's moderate internal consistency reflects limitations that are common in early-stage, open-ended, design-based assessments (Delahunty et al., 2020), underscoring the need for further refinement, larger and more diverse samples, and more advanced psychometric analyses - including factor analysis, construct validation, and multi-level reliability modeling - before the instrument can be considered fully established.

Motivation scale

The Motivation Scale was designed by the authors to measure four key motivational dimensions related to students' engagement with science learning: self-efficacy, collaboration, responsibility, and engagement. The instrument included 39 Likert-type items distributed across the four subscales, with each item rated on a five-point scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). Example items include: "I am confident I can solve difficult science problems" (self-efficacy), "I enjoy working with others on science projects" (collaboration), "I feel responsible for completing my science assignments on time" (responsibility), and "I am excited to learn new things in science that challenge me" (engagement).

Items for the scale were adapted from established theoretical frameworks and were reformulated to suit fourth-grade learners and to reflect the cultural and instructional context of the study. The items were reviewed by six experts in science education and psychology to assess their content validity, age-appropriateness, and alignment with the objectives of the STEM intervention. Feedback from the experts led to the rewording of some items, the elimination of redundancies, and the reassignment of several items to different subscales for better conceptual fit.

The scale was piloted with a group of 30 fourth-grade students, allowing the research team to assess item clarity and response variability. Minor adjustments were made following the pilot to improve the readability and comprehension of the items. The internal consistency of the final version of the scale was excellent, with a Cronbach's alpha of 0.90 overall, and subscale values ranging from 0.82 to 0.88. These results indicate strong reliability and coherence among items measuring the same construct (Field, 2009). The scale takes about 12 minutes for students to complete.

It is important to note that the scale was not designed to measure all SDT constructs comprehensively, nor to test SDT mechanisms causally. Instead, the selected subscales reflect practical motivational dimensions relevant to the intervention and grounded partly - but not exclusively - in SDT. The broader theoretical model presented earlier should therefore be interpreted as conceptual scaffolding rather than an empirically validated structure.

Procedure and data collection

Pre-tests were administered during the first week to establish baseline measures. The treatment group participated in the STEM-based instructional unit for six weeks, while the control group followed their standard science curriculum. To minimize practice effects, the Problem-Solving Test used tasks that were similar in structure but varied in content between pre- and post-testing. For instance, while the pre-test required students to design a device for an egg drop from 2, 4, and 6 meters, the post-test increased the complexity by raising the drop heights to 4, 6, and 8 meters and introducing new material constraints, thereby altering the problem-solving demands and requiring different design strategies. Classroom observations and teacher feedback were collected throughout the intervention to monitor fidelity and gather qualitative insights into student engagement. Post-tests and final surveys were administered during the last week to evaluate the intervention's impact.

Data analysis

Quantitative methods were used to analyze the results. Paired t-tests were conducted to measure within-group changes, while multivariate analysis of variance (MANOVA) assessed differences between the treatment and control groups. The Problem-Solving Test achieved moderate reliability (Cronbach's alpha = 0.66), while the Motivation Scale demonstrated strong reliability (Cronbach's alpha = 0.90). Inter-rater reliability for the Problem-Solving Test was robust, with a Cohen's kappa coefficient of 0.82, ensuring consistent evaluation across multiple raters (Field, 2009; Shaht et al., 2024b). These analyses provided insights into the intervention's effectiveness, emphasizing the impact of contextualized STEM activities on problem-solving skills and motivation (Shahat et al., 2022 a, b; Zhai et al., 2023).

In sum, this methodology was selected to effectively capture the cognitive and motivational impacts of the STEM-based instructional unit while highlighting the importance of cultural and environmental adaptations in STEM education.

RESULTS

To answer the research questions (RQ1–RQ3), we first confirmed baseline equivalence between groups on all outcomes. We then ran a two-way MANOVA with Group (experimental vs. control) and Gender (male vs. female) on two outcome sets: (a) Motivation (A, B, C, D, TOT_MOT) and (b) Problem-Solving (PI, FS, PL, PR, DEV, TOT_PS), followed by post-hoc univariate ANOVAs. Results are reported below for each RQ with direct reference to the relevant tables and figures.

Descriptive statistics

Normality assumptions were examined before conducting parametric tests. Based on visual inspection of histograms, Q-Q plots, and statistical tests for normality, the data were found to meet the assumptions required for parametric analyses. As a result, parametric tests such as t-tests and ANOVA/MANOVA were applied to analyze group differences in problem-solving skills and motivation scores. Table 4 gives an overview of Means, standard deviations of pre and post-scores on problem-solving skills, and the components of motivation for each gender and group (EXP/ CON)

Table 4

Means and standard deviations of pre and post scores for the problem-solving test and the components of motivation for each gender and group (EXP/ CON)

			Gender			
			1		2	
Group	Variables	Measurement	M	SD	M	SD
Con	Prob Solving	Pre_PI	2.11	1.13	1.50	1.04
		Pre_FS	1.39	1.31	2.04	1.20
		Pre_PL	1.96	0.96	1.79	0.99
		Pre_PR	2.39	0.88	2.32	0.86
		Pre_DEV	2.04	1.10	2.14	1.15
		Pre_TOTPS	9.89	3.19	9.79	2.47
		Post_PI	1.75	0.89	2.00	1.09
		Post_FS	1.71	0.81	2.00	0.82
		Post_PL	2.11	1.23	2.36	1.31
		Post_PR	2.25	0.84	2.04	0.96
		Post_DEV	2.21	0.96	2.11	1.10
		Post_TOTPS	10.04	2.22	10.50	2.60
	Motivation	Pre_A	2.43	0.32	2.44	0.40
		Pre_B	2.63	0.37	2.54	0.40
		Pre_C	2.54	0.41	2.46	0.36
		Pre_D	2.56	0.39	2.41	0.34
		Pre_Mot	2.54	0.33	2.46	0.31
		Post_A	2.51	0.41	2.50	0.38
		Post_B	2.56	0.39	2.70	0.21
		Post_C	2.53	0.37	2.61	0.21
		Post_D	2.45	0.42	2.47	0.24
		Post_Mot	2.51	0.32	2.57	0.20
Exp	Prob Solving	Pre_PI	2.06	1.03	1.50	0.79
		Pre_FS	2.00	1.06	1.79	1.07
		Pre_PL	2.26	1.15	2.21	1.03
		Pre_PR	2.16	0.82	2.18	0.77
		Pre_DEV	2.00	1.18	2.57	1.10
		Pre_TOTPS	10.48	2.10	10.25	2.61
		Post_PI	3.10	0.83	2.93	0.66
		Post_FS	2.10	0.65	2.04	0.51
		Post_PL	2.58	1.09	3.00	1.02
		Post_PR	2.45	0.85	2.64	0.56
		Post_DEV	2.45	0.68	2.39	0.88
		Post_TOTPS	12.68	2.40	13.00	2.05
	Motivation	Pre_A	2.46	0.29	2.53	0.30
		Pre_B	2.58	0.39	2.76	0.28
		Pre_C	2.70	0.33	2.54	0.25
		Pre_D	2.69	0.34	2.42	0.30
		Pre_Mot	2.62	0.27	2.55	0.22
		Post_A	2.57	0.28	2.63	0.33
		Post_B	2.60	0.31	2.74	0.21
		Post_C	2.77	0.22	2.74	0.14
		Post_D	2.75	0.28	2.76	0.27
		Post_Mot	2.69	0.19	2.72	0.16

Note: PI = Problem Identification, FS = Finding Solutions, PL = Planning, PR = Production, DEV = Development, TOTPS = Total Score for Problem-Solving, A = Self-Efficacy, B = Collaboration (Participation with Others), C = Responsibility, D = Engagement (Stimulating Environment), Mot = Total Score for Motivation, Con.=Control Group, Exp=Experimental Group, 1= Male, 2= Female

Pre-intervention analysis results

A pre-intervention analysis was conducted to assess the equivalence between the experimental and control groups at baseline for the dependent variables scores: Problem Solving (PI, FS, PL, PR, DEV, TOT_PS) and Motivation (A, B, C, D, TOT_MOT) (see Table 5). The results indicated no significant differences between the two groups for any of the variables. For problem solving, no significant differences were found for PI (t(113) = 0.036, p = 0.971), FS (t(113)= -0.833, p = 0.407), PL (t(113) = -1.878, p = 0.063), PR (t(113) = 1.217, p = 0.226), DEV (t(113) = -0.851, p = 0.396), and TOT_PS (t(113) = -1.106, p = 0.271) scores. As for Motivation, no significant differences were found for A (t(113) = -0.926, p = 0.357), B (t(113) = -1.227, p = 0.222), C (t(113) = -1.858, p = 0.066), D (t(113) = -1.185, p = 0.239), and TOT_MOT (t(113) = -1.637, p=0.105) scores. These findings suggest that the dependent variables for the experimental and control groups were statistically equivalent at baseline. Therefore, any subsequent differences observed in the post-intervention analysis can be attributed to the intervention itself.

Table 5

Pre-intervention analysis t-test results for baseline equivalence

Scale	Groupe	Mean	Std. Deviation	t	p
PI	con	1.80	1.12	0.036	0.971
	Exp	1.80	0.96		
FS	con	1.71	1.29	-0.833	0.407
	Exp	1.90	1.06		
PL	con	1.88	0.97	-1.878	0.063
	Exp	2.24	1.09		
PR	con	2.36	0.86	1.217	0.226
	Exp	2.17	0.79		
DEV	con	2.09	1.12	-0.851	0.396
	Exp	2.27	1.17		
TOTPS	con	9.84	2.83	-1.106	0.271
	Exp	10.37	2.33		
A	con	2.44	0.36	-0.926	0.357
	Exp	2.49	0.29		
B	con	2.59	0.38	-1.227	0.222
	Exp	2.67	0.35		
C	con	2.50	0.38	-1.858	0.066
	Exp	2.62	0.31		
D	con	2.49	0.37	-1.185	0.239
	Exp	2.56	0.34		
Mot	con	2.50	0.32	-1.637	0.105
	Exp	2.59	0.24		

RQ1: How does experiencing a culturally and contextually adapted STEM-based instructional unit impact the problem-solving skills of fourth-grade students in Oman?

To address this question, a two-way multivariate analysis of variance (MANOVA) was conducted, in which Group (experimental vs. control) and Gender (male vs. female) served as independent variables, and the six components of problem-solving skills (PI, FS, PL, PR, DEV, and TOT_PS) were treated as dependent variables (see Table 6). The results of the multivariate analysis revealed a statistically significant main effect of Group, Wilks' $\Lambda = 0.65$, $F(5, 107) = 11.78$, $p < .001$, partial $\eta^2 = .36$, indicating a substantial overall difference between the experimental and control groups in the combined set of problem-solving measures. In contrast, the main effect of Gender was not significant, $F(5, 107) = 0.90$, $p = .486$, partial $\eta^2 = .04$, suggesting that male and female students performed similarly on all problem-solving subscales. Likewise, the Group × Gender interaction was nonsignificant, $F(5, 107) = 1.03$, $p = .404$, partial $\eta^2 = .05$, indicating that the influence of the STEM-based intervention on problem-solving skills did not differ by gender.

Table 6

Two-way MANOVA results using group and gender as independent variables

Dep. Var.	Effect	Value	F	Hyp. df	Error df	p	partial η²
Motivation	Intercept	0.01	3238.55	5	107	0.000	0.993
	Group	0.77	6.26	5	107	0.000	0.226
	Gender	0.93	1.65	5	107	0.152	0.072
	Group * Gender	0.95	1.06	5	107	0.388	0.047
Problem Solving	Intercept	0.03	678.48	5	107	0.000	0.969
	Group	0.65	11.78	5	107	0.000	0.355
	Gender	0.96	0.90	5	107	0.486	0.040
	Group * Gender	0.95	1.03	5	107	0.404	0.046

Follow-up univariate analyses were performed to identify which specific components of problem solving contributed to the overall multivariate effect. As presented in **Table 7** and **Figure 2**, significant group differences were found in problem identification (PI), $F(1, 111) = 48.04$, $p < .001$, partial $\eta^2 = .30$; planning (PL), $F(1, 111) = 6.59$, $p = .012$, partial $\eta^2 = .06$; production (PR), $F(1, 111) = 7.01$, $p = .009$, partial $\eta^2 = .06$; and in the total problem-solving score (TOT_PS), $F(1, 111) = 34.93$, $p < .001$, partial $\eta^2 = .24$. These effects ranged from medium to large in magnitude, reflecting notable improvements among students who experienced the STEM unit. However, no statistically significant differences were observed in finding solutions (FS), $F(1, 111) = 2.51$, $p = .116$, partial $\eta^2 = .02$, or development (DEV), $F(1, 111) = 2.37$, $p = .126$, partial $\eta^2 = .02$. Overall, these results indicate that the intervention substantially enhanced students' ability to identify problems, plan solutions, and production through problem situations, leading to a marked improvement in their overall problem-solving performance compared to the control group.

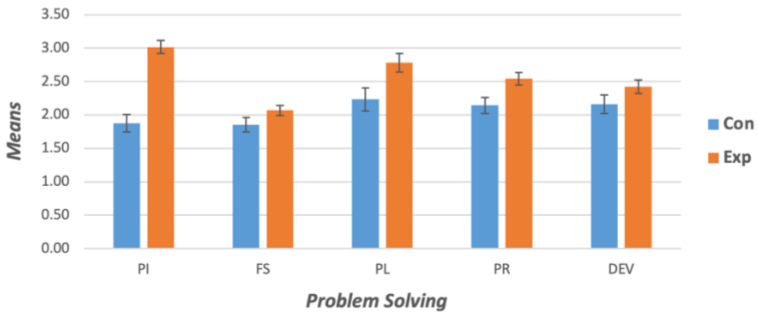
Table 7

Two-way MANOVA tests of between-subjects effects on problem solving

Source	Dep. Var.	Type III Sum of Squares	df	Mean Square	F	P	partial η²
Intercept	PI	685.49	1	685.49	886.64	0.000	0.889
	FS	441.69	1	441.69	885.16	0.000	0.889
	PL	723.82	1	723.82	533.29	0.000	0.828
	PR	631.19	1	631.19	942.70	0.000	0.895
	DEV	602.68	1	602.68	729.13	0.000	0.868
	TOT_PS	15320.23	1	15320.23	2821.36	0.000	0.962
Group	PI	37.14	1	37.14	48.04	0.000	0.302
	FS	1.25	1	1.25	2.51	0.116	0.022
	PL	8.94	1	8.94	6.59	0.012	0.056
	PR	4.69	1	4.69	7.01	0.009	0.059
	DEV	1.96	1	1.96	2.37	0.126	0.021
	TOT_PS	189.65	1	189.65	34.93	0.000	0.239
Error	PI	85.817	111	0.773			
	FS	55.388	111	0.499			
	PL	150.656	111	1.357			
	PR	74.320	111	0.670			
	DEV	91.749	111	0.827			
	TOT_PS	602.738	111	5.430			

Figure 2

The means of students' scores on problem-solving skills



RQ2: How does a STEM unit contextualize for Oman's educational and socio-environmental needs affect students' motivation and enthusiasm for learning science?

To examine the impact of the contextualized STEM unit on students' motivation, a two-way MANOVA was conducted with Group and Gender as independent variables and the five components of motivation (A, B, C, D, and TOT_MOT) as dependent variables (see Table 8). The multivariate results indicated a statistically significant main effect of Group, Wilks' $\Lambda = 0.77$, $F(5, 107) = 6.26$, $p < .001$, partial $\eta^2 = .23$, demonstrating that participation in the STEM unit led to significant improvements in the overall pattern of motivation variables. Conversely, the main effect of Gender was not significant, $F(5, 107) = 1.65$, $p = .152$, partial $\eta^2 = .07$, suggesting that male and female students reported comparable motivation levels. Similarly, the interaction between Group and Gender was not significant, $F(5, 107) = 1.06$, $p = .388$, partial $\eta^2 = .05$, indicating that the intervention influenced both genders in a similar manner.

Table 8

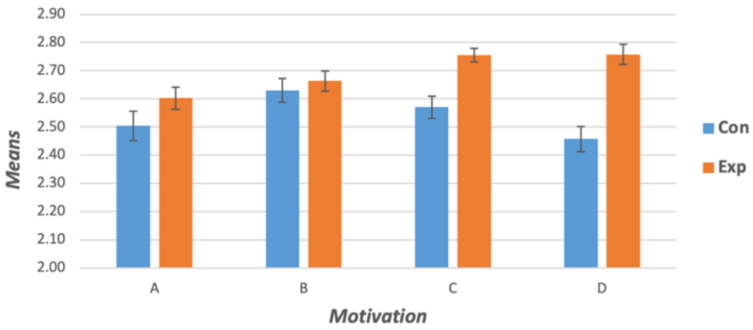
Two-way MANOVA tests of between-subjects effects on motivation

Source	Dep. Var.	Type III Sum of Squares	df	Mean Square	F	P	partial η^2
Intercept	Post_A	748.73	1	748.73	6100.15	0.000	0.982
	Post_B	804.85	1	804.85	9629.90	0.000	0.989
	Post_C	813.37	1	813.37	13292.05	0.000	0.992
	Post_D	780.35	1	780.35	8129.96	0.000	0.987
	Post_Mot	788.06	1	788.06	15555.43	0.000	0.993
Group	Post_A	0.29	1	0.29	2.35	0.128	0.021
	Post_B	0.04	1	0.04	0.48	0.492	0.004
	Post_C	0.97	1	0.97	15.91	0.000	0.125
	Post_D	2.59	1	2.59	27.02	0.000	0.196
	Post_Mot	0.78	1	0.78	15.35	0.000	0.121
Error	Post_A	13.62	111	0.12			
	Post_B	9.28	111	0.08			
	Post_C	6.79	111	0.06			
	Post_D	10.65	111	0.10			
	Post_Mot	5.62	111	0.05			

Univariate analyses were conducted to explore the source of the multivariate effect (Table 5). The results revealed no significant differences between groups in A, $F(1, 111) = 2.35$, $p = .128$, partial $\eta^2 = .02$, or B, $F(1, 111) = 0.48$, $p = .492$, partial $\eta^2 = .004$. However, significant effects were observed for C, $F(1, 111) = 15.91$, $p < .001$, partial $\eta^2 = .13$; D, $F(1, 111) = 27.02$, $p < .001$, partial $\eta^2 = .20$; and TOT_MOT, $F(1, 111) = 15.35$, $p < .001$, partial $\eta^2 = .12$. These results indicate that the contextualized STEM experience significantly enhanced students' sense of responsibility and engagement within a stimulating learning environment, as reflected in the significant differences observed for the Responsibility (C) and Engagement (D) components, as well as the Total Motivation score. In contrast, no substantial improvements were found in Self-Efficacy (A) or Collaboration (B), suggesting that the intervention's influence was more pronounced in fostering students' personal accountability and active involvement in learning rather than in altering their confidence or cooperative tendencies. Figure 3 graphically presents the mean motivation scores across groups, illustrating the consistent advantage of the experimental group over the control group.

Figure 3

The means of students' motivation scores



RQ3: How do male and female students differ in their response to the STEM instructional unit in terms of problem-solving skills and motivation?

This question aimed to determine whether students' gender moderated the effects of the STEM intervention on problem-solving skills and motivation. The results from the MANOVA analyses showed no statistically significant main effects of Gender for either problem-solving ($F(5, 107) = 0.90$, $p = .486$, partial $\eta^2 = .04$) or motivation ($F(5, 107) = 1.65$, $p = .152$, partial $\eta^2 = .07$). Likewise, the interaction effects between Group and Gender were nonsignificant across both domains—motivation ($F(5, 107) = 1.06$, $p = .388$, partial $\eta^2 = .05$) and problem solving ($F(5, 107) = 1.03$, $p = .404$, partial $\eta^2 = .05$). These findings collectively indicate that the influence of the STEM-based instructional unit was consistent across male and female students. In other words, the intervention benefited both genders equally, suggesting that the culturally contextualized design of the STEM activities was inclusive and equally effective for all participants, regardless of gender. Figures 2 and 3 further illustrate this pattern of similar gains for both male and female students.

DISCUSSION, IMPLICATIONS, AND LIMITATIONS

Discussion

While the study was informed by an integrated framework combining SDT, the EDP, and problem-solving cognition, only the specific motivational and cognitive constructs measured in the instruments were empirically examined. The broader theoretical links between SDT mechanisms and individual EDP phases were not directly tested and therefore remain conceptual (Ryan & Deci, 2000). Clarifying this distinction is essential to avoid overstating the explanatory power of the framework.

Within this conceptual framing, the findings are consistent with the idea that the iterative phases of the EDP can function as motivational scaffolds that support autonomy, competence, and relatedness - factors that may, in turn, enhance students' engagement and participation in problem-solving activities (Ryan & Deci, 2000). Although these mechanisms were not empirically validated in this study, the observed improvements in students' problem-solving performance and selected motivational dimensions align with the theoretical expectations of the integrated model. The results further demonstrate the potential value of culturally contextualized STEM instruction structured around the EDP, particularly in settings where linking engineering design to local cultural and environmental realities strengthens students' engagement (Shahat et al., 2024b; Shahat, M. A. & Al-Balushi, 2023; Shahat & Al-Amri, 2023). These findings are compatible with previous research emphasizing the benefits of inquiry-based, hands-on STEM activities in promoting critical thinking, engagement, and meaningful real-world application (Ahmed, 2016; Hafni et al., 2020; Razali et al., 2020; Zhai et al., 2023).

However, it is important to consider alternative explanations for the observed pattern of results. Improvements, especially in responsibility and engagement, may partly reflect novelty effects associated with introducing an unfamiliar instructional approach (Forbes et al., 2021). Students may have been motivated not only by the cultural authenticity of the tasks but also by the excitement of working with new materials, formats, or lesson structures. Similarly, teacher enthusiasm for the intervention could have influenced student outcomes despite efforts to standardize training and pacing guides. In addition, cultural norms around group work in Oman, which often emphasize social harmony, deference to authority, and unequal participation, may have shaped collaborative dynamics and contributed to the absence of significant gains in peer collaboration (Ambusaidi et al., 2022; Shahat & Al-Balushi, 2023). A more critical reading of the findings, therefore, requires acknowledging that contextualized STEM instruction is one plausible driver among several interacting social and pedagogical factors.

In addressing RQ1, which examines how a contextually adapted STEM unit influences students' problem-solving skills, the findings provide evidence of improvement. Post-intervention results revealed significant gains in the dimensions of problem identification, planning, and production (Table 7), confirming that aligning EDP-based challenges with students' lived experiences enhances their capacity to analyze, design, and refine solutions. Within the integrated framework, these gains reflect how the EDP fosters competence, one of the key needs identified in SDT, by allowing learners to apply scientific and engineering principles in iterative, feedback-rich contexts (Ryan & Deci, 2000). Unlike generic implementations of the EDP (Cross, 2004), the localized tasks used in this study - such as designing weather-resistant bird shelters using materials like sticks, clay, and felt - required students to account for Oman's climatic conditions and ecological realities (Alazri & Shahat, 2025; Shahat et al., 2022a). This task promoted ecological awareness, practical engineering, and resourcefulness within authentic environmental constraints. Similarly, the oil-spill cleanup challenge engaged students in creating low-cost filtration systems using familiar materials (cotton, sand, sponges), reinforcing both environmental responsibility and scientific reasoning through hands-on experimentation (Museum of Science, Boston, 2016; NASA, 2012).

In relation to RO2, which investigates how a contextualized STEM unit affects students' motivation, the study found statistically significant increases in responsibility and engagement (Table 8). These motivational gains are closely linked to the authenticity and relevance of the tasks presented. Students were not only solving problems; they were solving problems that felt real and locally meaningful. These findings are consistent with research emphasizing the motivational power of connecting STEM learning to cultural and environmental realities (Alsaeidan et al., 2023; Mohammed & Al-Harbi, 2024). Nonetheless, motivational gains may also have been supported by teacher encouragement or the perceived novelty of engineering-based activities, which warrants further investigation using classroom observations and teacher logs (Smith et al., 2022).

While positive effects were found in most motivational domains, self-efficacy and peer collaboration did not improve significantly. This suggests areas for further development. To address these outcomes, future iterations of the intervention should take research on reflective practice and learner-centered design into consideration (Schön, 2006; Tan et al., 2021). For example, they could incorporate guided self-reflection, teacher feedback loops, and structured group roles to better support students' confidence and interaction.

With respect to RO3, which examines gender-based differences in students' responses to the STEM unit, the analysis revealed no statistically significant differences in outcomes between male and female students across all measured dimensions. This suggests that the culturally adapted EDP created an equitable learning environment for students regardless of gender. Given ongoing concerns about gender disparities in STEM fields (Smith et al., 2022), these findings suggest there is value in using culturally grounded instructional approaches to mitigate such gaps. Future studies may explore whether similar inclusive effects extend to students of different socioeconomic backgrounds or school types (Idris et al., 2023).

Beyond its empirical contributions, the study offers practical guidance on how the EDP can be culturally grounded. While previous literature has often discussed the importance of cultural context in abstract terms, this research provides concrete instructional adaptations- such as embedding environmental challenges relevant to Oman - thereby offering a clear model for operationalizing culturally responsive pedagogy in STEM. In doing so, the study contributes to the growing body of research advocating for STEM instruction that is not only inquiry-based but also contextually rooted and culturally meaningful (Shahat et al., 2024 a, b, c; Bouzghia, 2024; Tabarés & Boni, 2023). It challenges the notion of the EDP as a culturally neutral framework and affirms that its effectiveness depends on how well it is integrated with learners' environments, resources, and values.

At the same time, the findings related to problem-solving performance should be interpreted cautiously. The problem-solving test used in this study was an exploratory, context-specific instrument with preliminary reliability and no factor-analytic validation (Field, 2009). As such, the PST provides initial insights rather than definitive measurement of problem-solving ability, and further validation is needed before it can be considered an established assessment tool (Shahat et al., 2024 b). This clarification is essential for avoiding over-interpretation while still acknowledging the promise of culturally grounded, performance-based assessment approaches.

In conclusion, this study makes an important contribution by demonstrating that the EDP is most impactful when grounded in the cultural and environmental realities of learners. Its primary contribution lies in showing how contextualized STEM instruction can enhance engagement and problem-solving experiences, while the exploratory assessment tools offer an initial direction for future measurement work. By critically considering alternative explanations - such as novelty effects, teacher influence, and cultural norms around group work - the study provides a more balanced interpretation of findings and identifies clear pathways for refining both instruction and research design. Ultimately, the study underscores that cultural relevance is not an add-on but a core element of effective, equitable, and transformative STEM education (Shahat, M. A. & Al-Balushi, 2023; Shahat & Al-Amri, 2023; PCAST, 2010).

Implications and limitations

The present study highlights significant implications for integrating STEM education in primary classrooms. The observed improvements in problem-solving skills demonstrate the value of inquiry-based, hands-on activities in fostering young learners' critical thinking and cognitive abilities (Bouzghia, 2024; Forbes et al., 2021; Razali et al., 2020). Additionally, the positive impact on responsibility and engagement underscores the potential of STEM education to promote intrinsic enthusiasm for learning, which is essential for sustained academic success, particularly in science-related fields (Ryan & Deci, 2000). These outcomes support the integrated theoretical framework proposed in this study, wherein the EDP serves as the mechanism that operationalizes SDT to connect motivation and problem-solving cognition. The absence of gender differences in the results further reinforces the inclusivity of STEM education as an equitable approach, offering opportunities for all students to succeed regardless of demographic variables (Shahat et al., 2022; 2024b).

Professional development programs are essential to maximize STEM education's effectiveness. Teachers must be equipped with strategies to facilitate collaborative, inquiry-based tasks that align with cultural norms and pedagogical goals (Shahat & Al-Amri, 2023). For instance, embedding explicit team-building protocols and reflective practices into teacher training could enhance students' self-efficacy and peer collaboration. Similarly, curriculum designers should integrate localized STEM tasks that reflect students lived experiences, fostering greater relevance and engagement (Mohammed & Al-Harbi, 2024; Yıldız & Ecevit, 2024).

Finally, future research should consider mixed methods designs to provide deeper insight into the ways students experience and interpret culturally grounded STEM activities. Classroom observations, teacher reflections, and student interviews would offer valuable qualitative dimensions to complement the quantitative findings.

However, several limitations must be acknowledged to contextualize the study's findings and strengthen the credibility of the claims. First, a central limitation concerns the psychometric adequacy of the PST. Although reviewed by experts and piloted with 30 fourth-grade students, the resulting Cronbach's $\alpha = .66$ indicates only moderate internal consistency - acceptable for exploratory work but below the threshold typically expected for confirmatory validation. No item-level or factor analysis has yet been conducted, as the primary objective at this stage was to design and pilot a culturally relevant performance-based assessment suited to Omani primary students. Consequently, the PST should be regarded as a preliminary prototype rather than a fully validated instrument. Future research will extend this work through formal validation procedures, including confirmatory factor analysis, item-response modeling, and cross-validation with larger, demographically diverse samples. These steps will help establish stronger reliability and construct validity before the instrument is used for high-stakes inferential purposes.

Second, the study relied on self-reported measures to assess student motivation, including a customized instrument adapted for the Omani primary school context. While the tool demonstrated content validity and internal consistency, it was developed primarily to support the evaluation of the culturally grounded intervention and should therefore be considered an early-stage, exploratory measure. Its preliminary nature introduces limitations, particularly regarding external reliability and comparisons with other contexts. Moreover, self-reported data - especially among younger students - may be sensitive to social desirability or limited metacognitive insight (Roebers, 2017), which could have influenced the accuracy of the reported motivational changes. Follow-up studies will therefore include more extensive psychometric validation. In line with the MEASURE framework (Kalkbrenner, 2021), future research should assess test–retest reliability, conduct confirmatory factor analysis, and establish broader criterion-related validity.

Third, methodological constraints inherent in the research design must also be acknowledged. A key limitation highlighted in methodological and psychometric literature is the challenge of drawing strong causal inferences from quasi-experimental designs conducted in naturally occurring classroom settings (Fraenkel et al., 2019). Although group equivalence was established at baseline, the nested structure of educational data - where students are clustered within classes and schools - introduces potential dependencies that the present design was not statistically powered to model. More explicit acknowledgment of these nested structures and the fact that classroom and teacher-level effects may have influenced outcomes is essential for a balanced interpretation. Future studies would benefit from employing multilevel analysis techniques to account for classroom-level variance and teacher-level influences.

A fourth limitation relates to the relatively small sample size and the study's focus on a specific geographic and cultural context. While this affords strong contextual relevance, it may constrain generalizability to wider populations. Replication across larger, more diverse samples is required to confirm the transferability of results (Idris et al., 2023). Additionally, the short-term nature of the intervention means that findings primarily reflect immediate learning outcomes; the long-term retention of problem-solving skills and motivational gains remains unknown. Longitudinal designs are therefore needed to examine the sustainability and developmental trajectory of these impacts over time (Zhai et al., 2023).

Finally, although the intervention enhanced students' sense of responsibility and engagement, it did not produce significant gains in self-efficacy or peer collaboration. These outcomes may have been constrained by limitations in task structure or facilitation strategies that did not sufficiently target these social-cognitive competencies. It is also possible that cultural norms around group dynamics, deference to authority, and role distributions in collaborative activities influenced the extent to which students engaged in peer interaction. Future research should incorporate explicit self-reflection protocols, formative peer feedback systems, and scaffolded collaboration models to better support these aspects. Mixed methods designs integrating observational and interview data would also help triangulate findings and provide deeper insight into group dynamics. Continued examination of how motivational and cognitive processes interact within design-based STEM instruction will help strengthen the theoretical and explanatory foundations of this research.

In sum, while the study provides important evidence of the cognitive and motivational benefits of contextually adapted STEM education, acknowledging these limitations highlights clear opportunities for methodological refinement and broader application. Collectively, these considerations contribute to the ongoing development of equitable, culturally responsive STEM practices within primary education.

Acknowledgement

The authors gratefully acknowledge the financial support provided by the Omani Ministry of Higher Education, Innovation, and Research. They also extend their sincere appreciation to Sultan Qaboos University for its kind support, as well as to the participating schools and students whose cooperation made this study possible.

Funding

This research was financially supported by the Omani Ministry of Higher Education, Innovation, and Research under Grant No. RC/RG-EDU/CUTM/22/01.

Ethical statement

Informed consent was obtained from all individual participants included in the study. The study was approved by the Ethical Review Board of the Ministry of Education in Oman (Approval No. 2823858754).

Competing interests

The authors declare that they have no competing interests.

Author contributions

Marwa Al-Hinai developed the research instruments and monitored the training process. *Mohamed A. Shahat* secured the funding, conceptualized the study, contributed to the methodology and data analysis, and wrote the original draft of the manuscript. *Ehab Omara* provided statistical expertise and conducted the data analysis. *Mahmoud M. Emam* contributed to the development of the research instruments and assisted in writing the original draft. *Sameh S. Ismail* assisted with data collection and monitored the training process. *Nabil Alhabsi* coordinated collaboration between the participating institutions and monitored the training process. *Khoula Alhosni* supported data collection and interpretation. *Mohammed Al-Amri* managed the project resources. *Amur Al-Yahmedi* provided critical feedback and contributed to shaping the research. *Yasser M. Fawzy* was responsible for data visualization. *Sulaiman M. Al-Balushi* contributed to the literature review and theoretical framework, supervised the project, and critically reviewed the manuscript.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

AI disclosure

Artificial intelligence tools were used solely to support language editing and improve the clarity of expression in this manuscript. No generative artificial intelligence tools were used in the study design, data collection, data analysis, or the substantive writing of the manuscript.

Biographical sketch

Dr. Marwa Al-Hinai is a Senior Educational Researcher at the Ministry of Education in the Sultanate of Oman. She holds a Ph.D. in Science Education (Curriculum and Instruction) from Sultan Qaboos University. Her expertise focuses on STEM education, curriculum development, and educational policy, with research interests in engineering design–based learning, STEM teacher professional development, program evaluation, quality assurance in education, and Building Learning Power. She is a co-author of the book *STEM Teaching Applications in Science Classrooms*.

Dr. Mohamed A. Shahat is an Associate Professor of Science Education at Sultan Qaboos University, Oman. He earned his Ph.D. in Physics Education from the University of Duisburg-Essen, Germany. His research addresses systemic challenges in education, with a particular focus on science and STEM/STEAM education, entrepreneurial learning, and the applications of artificial intelligence in learning, as well as the complex interplay of political, social, cultural, linguistic, and educational contexts. He has received multiple awards recognizing excellence in teaching, research, and editorial leadership, and he actively serves on the editorial boards of several leading international journals.

Prof. Mahmoud M. Emam is a Professor of Special and Inclusive Education at Sultan Qaboos University, Oman. His academic expertise includes inclusive education, assessment, and developmental and learning disabilities. His research examines inclusive school climates, teacher commitment, differentiated instruction, and Arabic-based assessment tools. He has led national projects on dyslexia screening and pragmatic language and teaches graduate courses in educational psychology and psycholinguistics. He has received national, regional, and international research awards and is actively involved in professional capacity-building initiatives across the Arab region.

Dr. Sameh S. Ismail is an Associate Professor of Educational Technology at the College of Education, Sultan Qaboos University. He previously served as Assistant Head of the Department of Curriculum and Instruction from 2018 to 2024. His research interests include educational technology, e-learning, e-portfolios, instructional design, and curriculum development, with a particular focus on technology-enhanced learning environments.

Mr. Nabil Alhabsi is a Senior Scientific Innovation Specialist at the Ministry of Education, Oman, and a Ph.D. researcher in Education Sciences at the University of Carthage. He holds a Master of Arts in Psychology (Measurement and Evaluation) from Sultan Qaboos University. His professional and research interests center on scientific innovation, integrated STEM education, future skills development, and intellectual property rights in educational contexts.

Dr. Khoula Alhosni is an Associate Professor of Mathematics Curricula and Teaching Methods at the College of Education, Sultan Qaboos University, where she was appointed in 2019. She holds a Ph.D. in Mathematics Education from Curtin University, Australia, and a master's degree from Sultan Qaboos University. She has received the Excellence in Performance Award from the Ijada System and formal recognition for excellence in teaching. She has also led a strategic national research project on education collaboration between governmental institutions. Her research interests include quality teaching, multilingualism, STEM education, emotional intelligence, and factors influencing academic achievement in mathematics and science.

Prof. Mohammed Al-Amri is a Professor of Art Education and former Head of the Department of Curriculum and Instruction at the College of Education, Sultan Qaboos University, Oman. He was a visiting scholar at Harvard University and a recipient of the Edwin Ziegfeld Award from InSEA. He holds an M.A. in Art Education from the University of Warwick and a Ph.D. from the University of Manchester. His research interests include art curriculum, program evaluation, creative thinking, STEAM education, quality standards, national curriculum development, field experiences, and academic accreditation.

Dr. Amur Al-Yahmedi is an Associate Professor of Mechanical Engineering at Sultan Qaboos University. He earned his Ph.D. from the University of California, Davis. His research interests include multibody dynamics, biomechanics, edutainment robotics, and human-centered robotic systems, with an emphasis on interdisciplinary applications in education and engineering.

Dr. Yasser M. Fawzy is an Associate Professor in the Department of Curriculum and Instruction, College of Education, Sultan Qaboos University. He holds a Ph.D. in Curriculum and Methods of Teaching Art Education. His research focuses on visual arts curriculum development, art teaching methodologies, and the professional preparation of art education teachers. He has published more than 60 scholarly works, co-authored a specialized book in art education, supervised numerous graduate theses, and is an active member of InSEA and a founding member of the Association for Education through Art in the Middle East and Africa (AmeSea).

Prof. Sulaiman M. Al-Balushi is a Professor of Science Education at Sultan Qaboos University. His research covers STEM education, gender differences in science learning, TIMSS achievement, and students' mental models. His expertise includes science teaching methodologies, mobile learning, and engineering practices in science education, with a focus on innovative instructional design to enhance student learning outcomes.

Disclaimer/Publisher's Note

REFERENCES

Abdullah, N., Kueh, Y. C., Kuan, G., Wong, M. S., & Lee, Y. Y. (2024). Psychometric evaluation of the abdominal bloating social support scale. *The Malaysian Journal of Medical Sciences: MJMS*, *31*(4), 138–148. https://doi.org/10.21315/mjms2024.31.4.11

Ahmed, H. F. S. (2016). The effectiveness of teaching a unit in light of STEM orientations in developing problem-solving skills and attitudes towards studying science among elementary students. *The Egyptian Journal of Science Education*, *19*(3), 129-176. https://doi.org/10.21608/MKTM.2016.113147

Alazri, A. A., & Shahat, M. A. (2025). Enhancing systems thinking in elementary science education: A STEM-based approach for fourth-grade learners. *International Electronic Journal of Elementary Education*, *17*(4), 629–641. Retrieved from https://iejee.com/index.php/IEJEE/article/view/2466

Alsaeidan, M. S. M. H., Alrashidi, M. H. K., & Almoji, A. M. S. (2023). A proposed program in science based on STEM learning orientations to develop achievement motivation among middle school students in Kuwait. *International Journal of Curriculum and Instructional Technology*, *12*(20), 127-149. https://doi.org/10.21608/ijcte.2023.210029.1087

Ambusaidi, A.K., Shahat, M.A., Al Musawi, A.S. (2022b). Science education in Oman. In: Huang, R., *et al.* Science Education in Countries Along the Belt & Road. *Lecture Notes in Educational Technology*. Springer, Singapore. https://doi.org/10.1007/978-981-16-6955-2_8

Bouzghia, K. (2024). A proposed vision to develop the teaching performance of physical science teachers in middle school in light of STEM education requirements. *Journal of Educational Sciences*, *5*(1), 270-289. https://journals.asmarya.edu.ly/jedu/index.php/jedu/article/view/89/91

Chowdhury, A., & Shil, N. C. (2021). Thinking 'qualitative' through a case study: Homework for a researcher. *American Journal of Qualitative Research, 5*(2), 190-210. https://doi.org/10.29333/ajqr/11280

Clausen, M. (2002). *Unterrichtsqualität: eine Frage der Perspektive? Empirische Analysen zur Übereinstimmung, Konstrukt- und Kritieriumsvalidität (Quality of instruction: a matter of perspective? Empirical analysis of compliance, construct and criterion).* Waxmann.

Cross, N. (2004). *The design process: Engineering design methods*. Wiley.

Darwish, S. M. (2024). Spatial abilities and engineering thinking among STEM school students and their relation to academic level. *The Scientific Journal of the Faculty of Education*, Assiut University, *40*(1), 305-332. https://doi.org/10.21608/mfes.2024.340358

Delahunty, T., Seery, N., & Lynch, R. (2020). Exploring problem conceptualization and performance in STEM problem solving contexts. *Instructional Science*, *48*(4), 395-425. https://doi.org/10.1007/s11251-020-09515-4

Field, A. (2009). *Discovering statistics using SPSS* (3rd ed.). SAGE Publications.

Forbes, A., Falloon, G., Stevenson, M., Hatzigianni, M., & Bower, M. (2021). An analysis of the nature of young students' STEM learning in 3D technology-enhanced makerspaces. *Early Education and Development*, *32*(1), 172-187. https://doi.org/10.1080/10409289.2020.1781325

Grewe, F. (2025). The need for diffraction in STEM-fields: An ethical feminist consideration of the concept of gender scripting. *Feminist Encounters: A Journal of Critical Studies in Culture and Politics*, *9*(2), 28. https://doi.org/10.20897/femenc/16786

Griethuijsen, R. A. L. F., Eijck, M. W., Haste, H., de Brok, P. J., Skinner, N. C., Mansour, N., & BouJaoude, S. (2015**).** Global patterns in students' views of science and interest in science. *Research in Science Education, 45*(4), 581–603. https://doi.org/10.1007/s11165-014-9438-6

Hafni, R. N., Rahmat, A., Priyandoko, D., & Mawarsari, V. D. (2020). The implementation of STEM-based learning to improve students' critical thinking skills. *Journal of Physics: Conference Series*, *1521*, 032030. https://doi.org/10.1088/1742-6596/1521/3/032030

Hox, J. J., Moerbeek, M., & van de Schoot, R. (2017). *Multilevel analysis: Techniques and applications* (3rd ed.). Routledge. https://doi.org/10.4324/9781315650982

Hsu, M., Purzer, S., & Cardella, M. E. (2011). Elementary teachers' views about teaching design, engineering, and technology. *Journal of Pre-College Engineering Education Research (J-PEER), 1*(2), Article 5. https://doi.org/10.5703/1288284314639

Idris, R., Govindasamy, P., Nachiappan, S., & Bacotang, J. (2023). Exploring the impact of cognitive factors on learning motivation and career in Malaysia's STEM education. *International Journal of Academic Research in Business and Social Sciences*, *13*(6), 1669-1684. https://doi.org/10.6007/IJARBSS/v13-i6/17227

Ismail, A. F., & Shahpo, S. M. (2025). The integrative learning approach in early childhood: A proposed framework based on STEM – a field study. *European Journal of STEM Education*, *10*(1), 30. https://doi.org/10.20897/ejsteme/17477

Kalkbrenner, M. T. (2021). A practical guide to instrument development and score validation in the social sciences: The MEASURE approach. *Practical Assessment, Research, and Evaluation*, *26*(1), Article 1. https://doi.org/10.7275/svg4-e671

Keller, J. M. (2009). *Motivational design for learning and performance: The ARCS model approach*. Springer

Khalil, R. Y., Tairab, H., Qablan, A., & Alarabi, K. (2023). STEM-based curriculum and creative thinking in high school students. *Education Sciences*, *13*(12), 1195. https://doi.org/10.3390/educsci13121195

Kim, Y., Glassman, M., & Williams, M. S. (2015). Connecting agents: Engagement and motivation in online collaboration. *Computers in Human Behavior*, *49*, 333-342. https://doi.org/10.1016/j.chb.2015.03.015

Mohammed, M. A. H., & Al-Harbi, N. N. S. (2024). A proposed project-based training program for teaching science and its effect on developing decision-making skills and achievement motivation for elementary students. *Journal of the Faculty of Education*, Tanta University, *90*(1), 594-622. https://doi.org/10.21608/mkmgt.2023.253202.1677

Museum of Science, Boston (2016). *Engineering is elementary: Engineering design process*. Museum of Science, Boston. https://www.eie.org/overview/engineering-design-process

NASA. (2012). *NASA's BEST activity buide: Engineering design process (grades 6-8)*. NASA.https://www.nasa.gov/wp-content/uploads/2012/09/630754main_nasasbestactivityguide6-8.pdf

PCAST (President's Council of Advisors on Science and Technology). (2010). *Prepare and inspire: K-12 education in science, technology, engineering, and math (STEM) for America's future*. Executive Office of the President. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf

Pellegrino, J. W., DiBello, L. V., & Goldman, S. R. (2016). A Framework for conceptualizing and evaluating the validity of instructionally relevant assessments. *Educational Psychologist*, *51*(1), 59–81. https://doi.org/10.1080/00461520.2016.1145550

Pontes, L. B., & Albuquerque, A. B. (2025). Who gets to intern? Demographic and institutional predictors of internship participation among international students. *European Journal of Education and Language Review*, *10*(1), 2. https://doi.org/10.20897/ejelr/17312

Razali, F., Talib, O., Sulaiman, S., & Kamarudin, N. (2020). The impact of STEM-based approach on students' performance and higher-order thinking skills. *Journal of Engineering Science and Technology*, *15*(3), 195-208. https://jestec.taylors.edu.my/Vol%2015%20issue%203%20June%202020/15_3_3.pdf

Roebers, C. M. (2017). Executive function and metacognition: Towards a unifying framework of cognitive self-regulation. *Developmental Review*, *45*, 31–51. https://doi.org/10.1016/j.dr.2017.04.001

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, *55*(1), 68-78. https://doi.org/10.1037/0003-066X.55.1.68

Schön, D. A. (2006). *The reflective practitioner: How professionals think in action*. Ashgate.

Shahat, M. A., Al Bahri, K. H., & Al-Balushi, S. M. (2024a). Enhancing elementary teacher preparation: The vital role of STEM-integrated experiences in Oman. In E. Cayton, M. Sanders, & J. Williams (Eds.), *Using STEM-focused teacher preparation programs to reimagine elementary education* (pp. 50-67). IGI Global. https://doi.org/10.4018/978-1-6684-5939-3.ch003

Shahat, M. A., Al-Balushi, S. M. & Al-Amri, M. (2024b). Measuring preservice science teachers' performance on engineering design process tasks: implications for fostering STEM education. *Arab Gulf Journal of Scientific Research,* 42(2), 259-279. https://doi.org/10.1108/AGJSR-12-2022-0277

Shahat, M.A., Al-Balushi, S.M., Abdullah, S., & Al-Amri, M. (2024c), Global perspectives and methodological innovations in STEM education: A systematic mapping analysis of engineering design-based teacher training, *Arab Gulf Journal of Scientific Research*, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/AGJSR-07-2023-0304

Shahat, M. A. & Al-Balushi, S. M. (2023). The development of STEM education in the Sultanate of Oman. In F. Alhashem, H. Pacheco-Guffrey, & J. Boivin (Eds.), *STEM education approaches and challenges in the MENA region* (pp. 56-73). IGI Global. https://doi.org/10.4018/978-1-6684-6883-8.ch003

Shahat, M. A., Al Amri, M. (2023). Science teacher preparation in Oman: Strengths and shortcomings related to STEM education. In: Al-Balushi, S. M., Martin-Hansen, and L., Song, Y. (Eds.), *Reforming science teacher education programs in the STEM Era*. Palgrave Studies on Leadership and Learning in Teacher Education. Palgrave Macmillan. https://doi.org/10.1007/978-3-031-27334-6_10

Shahat, M. A., Al-Balushi, S. M., & Al-Amri, M. (2022). Investigating pre-service science teachers' self-efficacy beliefs for teaching science through engineering design processes. *Interdisciplinary Journal of Environmental and Science Education, 18*(4), 2291. https://doi.org/10.21601/ijese/12121

Shahat, M. A., Ohle, A., & Fischer, H. E. (2017). Evaluation of a teaching unit based on a problem-solving model for seventh-grade students. *Zeitschrift für Didaktik der Naturwissenschaften, 23*, 205–224. https://doi.org/10.1007/s40573-017-0068-1

Shahidullah, K. K., & Hossain, M. R. (2022). Designing an integrated undergraduate disaster STEM curriculum: A cultural shift in higher education curriculum development in Bangladesh. *Journal of Ethnic and Cultural Studies*, *9*(1), 265–280. https://doi.org/10.29333/ejecs/1042

Smith, K., Maynard, N., Berry, A., Stephenson, T., Spiteri, T., Corrigan, D., Mansfield, J., Ellerton, P., & Smith, T. (2022). Principles of Problem-Based Learning (PBL) in STEM Education: Using Expert Wisdom and Research to Frame Educational Practice. *Education Sciences*, *12*(10), 728. https://doi.org/10.3390/educsci12100728

Soros, P., Ponkham, K., & Ekkapim, S. 2018. The results of STEM education methods for enhancing critical thinking and problem solving skill in physics the 10th grade level. *In AIP Conference Proceedings 1923*(1). AIP Publishing.

Tabarés, R., & Boni, A. (2023). Maker culture and its potential for STEM education. *International Journal of Technology and Design Education*, *33*, 241-260. https://doi.org/10.1007/s10798-021-09725-y

Tan, A.-L., Ong, Y. S., Ng, Y. S., & Tan, J. H. J. (2021). STEM problem solving: Inquiry concepts and reasoning. *Science & Education*, *32*, 381-397. https://doi.org/10.1007/s11191-021-00310-2

Tewolde, A. I. (2024). Re-conceptualizing insider/outsider positionalities in migration research as 'liquid positionalities': An analytical tool for migration scholars. *Social Sciences*, *13*(1), 30. https://doi.org/10.3390/socsci13010030

Yang, D., & Baldwin, S. J. (2020). Using technology to support student learning in an integrated STEM learning environment. *International Journal of Technology in Education and Science, 4*(1), 1-11. https://doi.org/10.46328/ijtes.v4i1.22

Yıldız, M., & Ecevit, T. (2024). Impact of STEM on primary school students' 21st century skills, NOS, and learning experiences. *Asian Journal of Instruction*, *12*(2), 21-37. https://doi.org/10.47215/aji.1395298

Zainil, M., Kenedi, A. K., Rahmatina, Indrawati, T., & Handrianto, C. (2023). The influence of a STEM-based digital classroom learning model and high-order thinking skills on the 21st-century skills of elementary school students in Indonesia. *Journal of Education and E-Learning Research*, 10 (1), 29-35. https://doi.org/10.20448/jeelr.v10i1.4336

Zhai, X., Neumann, K., & Krajcik, J. (2023). Editorial: AI for tackling STEM education challenges. *Frontiers in Education*, *8*, Article 1183030. https://doi.org/10.3389/feduc.2023.1183030

