European Journal of Science and Mathematics Education, 2026, **14**(1), 148-161
ISSN: 2301-251X (Online)

OPEN ACCESS

Research Article

Enhancing third-grade students' academic achievement and scientific attitudes through experimental demonstrations on alternative energy in Arab-community schools

Muhamad Hugerat [1,2*]
0009-0003-8455-5256

Monaea Lafi [1]
0009-0009-9045-6469

Sare Asli [2,3]
0000-0002-3754-4613

[1] The Academic Arab College for Education in Israel–Haifa, Haifa, ISRAEL
[2] The Science Education Center, The Institute of Applied Research, The Galilee Society, Shefa-Amr, ISRAEL
[3] Al-Qasemi Academic College, Baqa al-Gharbiyye, ISRAEL
[*] Corresponding author: muha4@arabcol.ac.il

Citation: Hugerat, M., Lafi, M., & Asli, S. (2026). Enhancing third-grade students' academic achievement and scientific attitudes through experimental demonstrations on alternative energy in Arab-community schools. *European Journal of Science and Mathematics Education, 14*(1), 148-161. https://doi.org/10.30935/scimath/17869

ARTICLE INFO

Received: 1 Jun 2025
Accepted: 4 Nov 2025

ABSTRACT

This study investigates the impact of experimental demonstrations on the academic achievement, conceptual understanding, and attitudes toward science of third-grade students, with a focus on alternative energy topics. Conducted in an Arab-community middle school in Northern Israel, the research involved 120 students, divided equally into an experimental group ($n = 60$) and a control group ($n = 60$). The experimental group received instruction through hands-on demonstrations related to solar, wind, hydropower, biomass, and geothermal energy, while the control group was taught using traditional methods. Employing a mixed-methods design, data were collected through academic tests, attitudinal questionnaires, and semi-structured interviews. The results showed that students in the experimental group achieved significantly higher post-intervention scores (mean [M] = 82.62, standard deviation [SD] = 12.93) compared to the control group (M = 71.28, SD = 15.06), with a statistically significant difference (t [118] = -2.58, $p < .01$). Additionally, the experimental group demonstrated a significantly greater understanding of alternative energy concepts (M = 3.27, SD = 0.42) than the control group (M = 2.82, SD = 0.53), (t [58] = -3.42, $p < .001$). Attitudinal measures also favored the experimental group (M = 3.34, SD = 0.44) over the control group (M = 3.09, SD = 0.64), with a significant difference (t [118] = -2.12, $p < .05$). These results advocate for integrating demonstration-based teaching to enhance science education outcomes, particularly in sustainability topics.

Keywords: alternative energy, experimental demonstrations, science education, academic achievement, student attitudes, experimental demonstrations

INTRODUCTION

Science and technology play a crucial role in addressing the global energy crisis and promoting sustainable development (Clark, 2025; Cole et al., 2023). A significant challenge is the increasing demand for clean, renewable energy that is environmentally friendly, which has led to a focus on alternative energy sources, such as solar, wind, and geothermal (Altun & Ozsevgec, 2025; Sapochetti, 2025; Shahid et al., 2019). These renewable sources are essential for future energy needs (Pambudi et al., 2025; Papilaya & Tuapattinaya, 2022). Concurrently, science education is vital for raising awareness among young learners (Sapochetti, 2025).

Academic achievement is influenced by factors such as teaching methods (Batni & Junaini, 2025; Khan et al., 2025). Innovative approaches, such as experimental demonstrations, enhance engagement and understanding (Kotsis, 2024; Mayes & Myers, 2015). These hands-on activities help students grasp complex concepts and foster a positive attitude toward science, potentially improving their academic performance (King et al., 2015; Larassati et al., 2025).

The rationale for this study stems from the growing gap between the theoretical teaching of science and the need for engaging, meaningful, and future-oriented education (Clark, 2025; Cole et al., 2023). Despite the importance of environmental topics, such as alternative energy, they remain underrepresented in elementary and middle school curricula, particularly in regions with limited educational resources (Batni & Junaini, 2025; Khan et al., 2025; Kyere, 2017). Moreover, traditional methods of science instruction often fail to ignite curiosity or foster deeper understanding among students (Sapochetti, 2025; Shahid et al., 2019). In contrast, experimental demonstrations offer a promising avenue for bridging this gap by turning abstract ideas into tangible experiences (Kotsis, 2024; Mayes & Myers, 2015; Pambudi et al., 2025). When students are presented with demonstrations of how solar panels generate electricity or how wind turbines work, they begin to make real-world connections to scientific concepts, enhancing both motivation and comprehension (Anzum et al., 2025; Assaf, 2018). This is especially important at a young age, such as third grade, when cognitive curiosity is high and foundational attitudes toward learning are formed (Pambudi et al., 2025; Papilaya & Tuapattinaya, 2022). The current study aims to investigate whether integrating experimental demonstrations into science lessons can lead to improved academic outcomes and more meaningful classroom engagement (Altun & Ozsevgec, 2025; Sapochetti, 2025; Shahid et al., 2019; Solihat et al., 2024).

The significance of this study lies in its ability to impact science education and curriculum development, especially in the context of sustainable energy solutions. It emphasizes the importance of equipping students with scientific literacy to help them make informed environmental decisions.

The preparation of science teachers should include historical and philosophical elements, as demonstrated through practical teaching activities. For example, lessons on alternative energy can incorporate the development history of solar and wind technologies while examining societal needs and philosophical perspectives. This approach fosters an understanding of science as an evolving field influenced by social and cultural issues.

The study provides a practical model for teachers, particularly in under-resourced environments, suggesting low-cost demonstrations to enhance learning. It advocates for a hands-on, meaningful science education aligned with global sustainability needs, preparing a new generation of environmentally conscious, scientifically literate individuals.

This research aims to redefine 21st century science education by moving beyond content delivery to adopt teaching strategies that foster critical thinking, creativity, and ethical considerations in scientific literacy. This responsibility falls on educators and policymakers to ensure that science education incorporates civic and moral dimensions.

LITERATURE REVIEW

Science Education and Its Role in Developing Scientific Literacy

Science education is a critical component of modern schooling, essential not only for knowledge but also for developing critical thinking skills (Kyere, 2017; Larassati et al., 2025). Through science instruction, students learn to inquire, investigate, and draw evidence-based conclusions (Flener Lovitt et al., 2025; Henderson et al., 2025). Modern science education emphasizes curiosity and emotional engagement, aiming to create meaningful learning experiences (Clark, 2025; Cole et al., 2023). Teachers are challenged to make science relevant by connecting it to everyday life and societal issues (Batni & Junaini, 2025; Miladinović, 2025). Effective education integrates scientific content with inquiry and critical analysis, helping students explore the world scientifically (Namdar & Shen, 2018). In Israel, science education is highly valued for preparing students for a technologically advanced society (Anzum et al., 2025). Science educators aim to build scientifically literate students who can think analytically and creatively–a necessity in the 21st century (Bai et al., 2016). The teacher's role encompasses facilitating hands-on learning and adapting instructional methods to accommodate diverse learners (Henderson et al., 2025).

In recent years, the field of science education has advanced toward a more nuanced understanding of how scientifically literate citizens are developed–not simply as recipients of content knowledge, but as active knowledge builders engaging in inquiry and reasoning. For example, Urdanivia Alarcón et al. (2023) undertook a comprehensive review of inquiry-based learning (IBL) in K-12 science, observing that IBL supports students' development of research skills, data interpretation, and model construction, rather than mere factual recall. Their synthesis highlights the shift from "teacher-led content delivery" toward scaffolding students to pose questions, collect evidence, and conclude. This evolution in emphasis underscores the importance of framing science education in this study not only as a matter of knowledge acquisition, but also as a means of shaping attitudes, engagement, and reasoning capacity–particularly relevant when teaching energy systems and sustainability. This perspective supports scientific literacy as inclusive of conceptual understanding, attitude, and future intent.

These concepts align with the science: philosophy, history, and education series, which emphasizes the integration of philosophical and historical dimensions of science in education. This framework encourages understanding of how scientific knowledge is created and applied, situating educators within a context that combines content with metacognition to enhance effective teaching strategies.

Moreover, recent meta-analytic and review evidence point to the added value of integrating emotion and engagement into science instruction. A review of pedagogical innovations by Prajapati (2025) found that while many strategies emphasize cognitive outcomes, a growing number focus on student affect–interest, motivation, and joy in science learning. The review documented increased attention to strategies such as storytelling, contextualized phenomena, and student agency. These findings emphasize attitudes toward science and the affective domain, reinforcing the importance of instructional designs (such as demonstrations) that do more than transmit content–they engage learners emotionally and socially. Thus, the inclusion of attitudinal measures is well supported in the evolving literature.

Teaching Science Through Demonstrations: Enhancing Understanding and Engagement

The instructional technique of demonstrations has received renewed empirical attention, particularly in light of concerns that demonstrations sometimes fail to engage participants actively. Agustian (2025) explored a demonstration-based intervention in preservice science teacher education and emphasized that for demonstrations to be practical, they must be embedded within an inquiry framework rather than shown. Similarly, Nikitin et al. (2025) compared lecture demonstrations, science-show formats, and hands-on work, finding that while science-shows generated high interest, they were perceived as less valuable than authentic hands-on tasks–though girls particularly preferred the show format. These findings suggest that the use of "hands-on demonstration" rather than passive demonstration aligns with this evolving evidence: realizing the full potential of demonstrations involves interaction, reflection, and alignment with students' prior conceptions.

One effective teaching strategy in science classrooms is the use of demonstrations (Reed et al., 2021; Russ & Turnbull, 2025). This approach presents scientific principles through live experiments, models, or simulations that students can observe and interact with (Haynes et al., 2024; Henderson et al., 2025). Demonstrations bridge the gap between theory and practice, making abstract concepts more tangible (Altun & Ozsevgec, 2025; Papilaya & Tuapattinaya, 2022). They enhance student engagement, particularly when visually impressive or connected to real-life applications (Namdar & Shen, 2018; Shahid et al., 2019). By simplifying complex ideas, teachers can foster more profound understanding and retention (Henderson et al., 2025; King et al., 2015). Demonstrations also encourage students to ask questions and develop scientific reasoning (Haynes et al., 2024). Unlike traditional lectures, this method fosters a dynamic learning environment that promotes greater student involvement (Solihat et al., 2024). Studies indicate that demonstrations promote conceptual change in subjects like chemistry and physics, helping students overcome alternative conceptions (Kyere, 2017; Omagwa, 2022). Additionally, in inclusive classrooms, hands-on demonstrations cater to diverse learning styles, making science accessible to all learners (Alfiah et al., 2025; Anzum et al., 2025).

Recent systematic review work has attempted to unpack the mechanisms whereby demonstration-type instruction influences learning. For instance, Oliveira and Bonito (2023) conducted a systematic review of "practical work" (which includes demonstrations, hands-on labs, and manipulation of materials). They identified five major limitation categories–among them the mismatch between the design of the task and authentic scientific practice, and teachers' preparedness to orchestrate reflections after the activity. Their work cautions that simply exposing students to materials is insufficient; without scaffolding, reflection, and linking to underlying concepts ("minds-on"), the benefits are undermined. This suggests the importance of embedding students' discussion, prediction, and explanation phases–not just the spectacle of demonstration alone.

Experimental Learning and Its Impact on Academic Achievement

Experiential learning or IBL involves active student participation, enabling learners to explore scientific phenomena firsthand, observe outcomes, and draw conclusions (Astuti, 2023; Bai et al., 2016). This method, effective even at the elementary level, fosters curiosity, critical thinking, and problem-solving skills (Alfiah et al., 2025; Mulyani et al., 2025). By engaging in practical investigations, students develop hypotheses, collect and interpret data, and enhance their scientific literacy (Frimpong et al., 2025). Experimental learning is associated with enhanced academic performance, mainly when students manipulate variables and experience cause-and-effect relationships (Astuti, 2023). Science laboratories and classroom experiments bolster conceptual understanding and skills in observation, measurement, and analysis (Haynes et al., 2024). Additionally, hands-on activities encourage collaboration and communication among students, fostering a sense of community (Mulyani et al., 2025). Overall, the structure of scientific experiments cultivates discipline and perseverance, contributing to academic success across subjects (Alfiah et al., 2025).

Alternative Energy as a Context for Science Education

The topic of alternative energy offers a strong disciplinary context for science education, and recent literature emphasizes its capacity to integrate STEM, environmental literacy, and sustainability thinking. For example, Prajapati (2025) examined elementary learners' understanding of solar energy systems and emphasized that renewable-energy contexts provide rich opportunities for linking systems thinking, real-world applications, and cross-disciplinary reasoning. Moreover, Wörner et al. (2022) synthesized literature on combining real and virtual experimental experiences, finding that blended modes in energy topics increased conceptual understanding and interest. Together, these lines of research strengthen the rationale for choosing alternative energy as a focus: it is not just topical and societally relevant, but pedagogically rich for fostering scientific literacy, inquiry, and attitudinal growth.

Teaching science through alternative energy addresses a crucial global challenge: finding sustainable energy sources (Astuti, 2023; Frimpong et al., 2025). This topic covers solar, wind, water, geothermal, and biomass energy, linking physics, chemistry, environmental science, and technology (Clark, 2025; Isham et al., 2025; Mulyani et al., 2025; Papilaya & Tuapattinaya, 2022). With rising environmental concerns, integrating renewable energy into the curriculum is essential (Anzum et al., 2025; Clark, 2025; Flener Lovitt et al., 2025). It helps students understand scientific principles, practical applications, and environmental impacts (Omagwa, 2022; Palines et al., 2025). Engaging in experiments, such as observing solar panels and wind turbines, enhances their understanding of energy transformation and sustainability (Isham et al., 2025; Mayes & Myers, 2015; Miladinović, 2025). Such learning fosters creativity through project-based assignments, encouraging students to design and present their energy solutions (Astuti, 2023; Awwalina et al., 2025). Ultimately, this relevance boosts motivation and interest in STEM fields (Palines et al., 2025; Papilaya & Tuapattinaya, 2022; Reed et al., 2021; Russ & Turnbull, 2025).

Academic Achievement in Science and Influencing Factors

Academic achievement in science is influenced by personal, familial, and educational factors (Clark, 2025; Cole et al., 2023). Personal traits such as motivation, discipline, and prior knowledge are crucial for student performance (Kotsis, 2024; Mayes & Myers, 2015). External factors, such as teaching quality, classroom environment, and parental support, also significantly impact learning outcomes (Sapochetti, 2025; Shahid et al., 2019). Effective teaching methods that align with students' needs, particularly interactive and student-centered strategies, foster greater engagement and understanding, leading to improved academic results (Batni & Junaini, 2025; Khan et al., 2025; Kyere, 2017). Schools that promote scientific inquiry and provide hands-on learning opportunities contribute to student success (Pambudi et al., 2025; Papilaya & Tuapattinaya, 2022). Family involvement in education is key; students with supportive parents are more likely to excel (Anzum et al., 2025; Assaf, 2018). Additionally, the school's structure, including curriculum design and assessment, shapes students' perceptions and approaches to learning (King et al., 2015; Kotsis, 2024). Thus, fostering academic success in science requires a holistic approach that empowers students through engaging and meaningful learning experiences (Clark, 2025; Cole et al., 2023).

The Contribution of Demonstrations to Understanding, Attitudes, and Classroom Dynamics

Experimental demonstrations in science classrooms have been shown to influence students' attitudes and reshape classroom dynamics positively (Anzum et al., 2025; Cole et al., 2023). Active engagement often leads to more favorable perceptions of the subject and stronger teacher-student relationships (Flener Lovitt et al., 2025; Henderson et al., 2025). These demonstrations can reinvigorate lessons, fostering a culture of questioning and exploration (Batni & Junaini, 2025; Clark, 2025). When learning is interactive and enjoyable, students feel more comfortable participating and sharing ideas (Namdar & Shen, 2018; Russ & Turnbull, 2025). Moreover, shared experiences during demonstrations promote collaboration and enrich the learning environment (Kyere, 2017). The excitement of demonstrations helps strengthen memory and understanding, building confidence and curiosity essential for lifelong learning (Alfiah et al., 2025). Thus, demonstrations not only enhance academic performance but also shape students' perceptions of science and their sense of belonging in the classroom (Clark, 2025; Henderson et al., 2025).

Finally, the interplay between demonstration-based instruction and student attitudes is now better documented. Ramadani (2025) investigated physics instruction in primary schools and found that demonstration-rich environments increased interest, motivation, and preparation for more advanced laboratory tasks. In addition, Cleopas and Igbojinwaekwu (2024) compared demonstration and discussion teaching methods and found that the demonstration method enhanced achievement and attitudes, although retention gains varied. These findings highlight the dual potential of demonstrations: cognitive (understanding and achievement) and affective (attitude and interest). These findings align with and contribute to a growing body of empirical work that positions demonstration-based teaching as a viable lever for both academic and attitudinal gains in science.

THE PRESENT STUDY

Research Topic

This study examines the effect of experimental demonstrations on the academic achievement of third-grade students in the context of alternative energy sources, specifically solar, wind, hydropower, biomass, and geothermal energy.

Research Objectives

1. Informed by the theoretical foundations outlined in the literature review, the present study seeks to achieve the following objectives:
2. To examine whether the use of experimental demonstrations in teaching the topic of alternative energy significantly influences students' academic achievement.
3. To explore the relationship between students' conceptual understanding of alternative energy and their engagement with scientific demonstrations during the learning process.

Research Question

To what extent, and in what ways, does the integration of experimental demonstrations in the teaching of alternative energy (solar, wind, water, biomass, geothermal) affect the academic performance of third-grade students?

Research Hypotheses

1. Students who are taught alternative energy topics through experimental demonstrations will exhibit higher academic achievement compared to their peers who receive instruction through traditional methods without demonstrations.
2. Students exposed to the demonstration-based teaching approach will demonstrate a greater depth of understanding of alternative energy concepts than those taught without demonstrations.
3. Students who learn through experimental demonstrations will display more positive attitudes toward science, particularly about the role of women in science, than students who are not exposed to experimental teaching methods in the context of alternative energy.

METHODS AND METHODOLOGY

Study Population

The study was conducted with its central objective, involving two tenth-grade classes from a middle school located in the northern region of the country, which represents the Arab community. A total of 60 students participated in the study, comprising 32 boys and 28 girls. The participants were relatively homogeneous in terms of their academic level and socioeconomic status. The research employed a quasi-experimental design, with one class designated as the experimental group and the other as the control group. The independent variable was the instructional method–specifically, the use of experimental demonstrations–while the dependent variable was the students' academic achievement. The experimental group received instruction using the demonstration method, whereas the control group was taught the duplicate content through traditional, non-experimental means.

Research Instruments

Various research tools were used to collect both quantitative and qualitative data. A perception questionnaire, adapted from Basheer et al. (2016), was used to assess students' attitudes toward demonstrations in the chemistry classroom. This included ten items focused on student responses within the experimental group. Additionally, semi-structured interviews with select students provided insights into their comprehension, satisfaction, motivation, and attitudes toward science.

A multiple-choice test with 15 questions on oxidation-reduction and electrolysis was used to evaluate academic achievement. The questions were derived from textbooks and previous exams, with refinement from two chemistry education experts who ensured the test aligned with Bloom's taxonomy and measured both factual knowledge and higher-order thinking.

The attitude questionnaire had a Cronbach's alpha of 0.78, indicating good internal reliability. Quantitative data were analyzed using independent-samples t-tests, while qualitative data from interviews underwent thematic analysis to identify patterns and reflections on the demonstrations.

Research Methodology and Its Suitability

This study employed a mixed-methods research design, combining both quantitative and qualitative approaches to provide a comprehensive understanding of the research phenomenon. The quantitative aspect focused on measuring the academic achievement and attitudes of students before and after the intervention, enabling a statistical comparison between the control and experimental groups (Aramo-Immonen, 2013; Doyle et al., 2016; Schoonenboom & Johnson, 2017). This approach provided objective evidence regarding the effectiveness of the demonstration method in improving learning outcomes. The qualitative aspect, by contrast, enabled a more nuanced exploration of student perspectives, emotional engagement, and personal reflections on the learning process (Doyle et al., 2016; Schoonenboom & Johnson, 2017). Through the use of semi-structured interviews, the researcher was able to delve into students' attitudes and conceptual understanding of the subject matter (Aramo-Immonen, 2013; Doyle et al., 2016).

This methodological approach was deemed highly appropriate for the research topic, as it enabled the triangulation of data from multiple sources and perspectives (Schoonenboom & Johnson, 2017). The use of

Table 1. Distribution of participants by group affiliation

Group	Number of participants (N)	Percentage (%)
Experimental	60	50
Control	60	50

Table 2. Differences between experimental and control groups in academic achievement

Academic achievement	Control group (n = 60): M (SD)	Experimental group (n = 60): M (SD)	t (118)	Significance
Pre-intervention	69.82 (16.35)	74.25 (15.44)	-1.03	Not significant
Post-intervention	71.28 (15.06)	82.62 (12.93)	-2.58	p < .01

demonstrations in science education–particularly in the context of alternative energy–requires not only measurable academic outcomes but also an understanding of students' engagement and cognitive development. The integration of qualitative insights and quantitative metrics offered a holistic view of how the demonstration method influences both learning and attitudes toward science. The combination of these methods enhanced the validity of the findings and allowed for a richer interpretation of the outcomes (Doyle et al., 2016; Schoonenboom & Johnson, 2017).

Research Procedure

The study investigated an instructional unit on alternative energy taught through demonstration methods at a middle school in Northern Israel. After receiving administrative approval, a qualified teacher was trained to implement the unit, which was delivered in two third-grade classes.

Initially, students completed a baseline questionnaire to assess their perceptions of demonstrations, followed by semi-structured interviews and a knowledge-based questionnaire on alternative energy sources. Over the course of 1.5 months, the teacher conducted 10 lessons covering various alternative energy sources, including solar, wind, hydropower, biomass, and geothermal.

Participants were divided into a control group, taught with conventional methods, and an experimental group, which was taught using demonstrations. Following the unit, both groups completed a post-intervention questionnaire and participated in follow-up interviews to assess their experiences.

The study aimed to evaluate the impact of experimental demonstrations on students' academic performance, understanding, and attitudes toward science, using both qualitative and quantitative analyses to determine the effectiveness of hands-on activities in the science curriculum.

FINDINGS

This study examined the effect of experimental demonstrations on students' academic achievement, conceptual understanding, and attitudes toward science within the context of alternative energy education. A total of 120 ninth-grade students participated, evenly divided between an experimental group (n = 60) and a control group (n = 60). The experimental group received instruction using demonstration-based methods, while the control group received traditional instruction without experimental integration. The variables measured included academic achievement (pre- and post-intervention), levels of understanding, and attitudes toward science. The internal consistency of the measurement instruments was confirmed via Cronbach's alpha, and hypothesis testing was conducted using independent samples t-tests. **Table 1** shows the distribution of participants by group affiliation.

Hypothesis 1. Impact on Academic Achievement

To examine whether the use of experimental demonstrations significantly improved students' academic achievement, an independent samples t-test was conducted comparing the pre- and post-intervention academic performance scores of the experimental and control groups.

The results in **Table 2** reveal no significant difference in academic achievement between the groups prior to the intervention, confirming that both groups started from a similar baseline. However, following the intervention, the experimental group demonstrated significantly higher academic achievement compared to the control group (t [118] = -2.58, p < .01). This finding confirms the first hypothesis. The demonstration-based teaching method had a substantial and positive effect on students' academic performance.

Table 3. Differences between experimental and control groups in conceptual understanding

Understanding level	Control group (n = 30): M (SD)	Experimental group (n = 30): M (SD)	t (58)	Significance
Pre-intervention	2.86 (.67)	2.77 (.53)	0.714	Not significant
Post-intervention	2.82 (.53)	3.27 (.42)	-3.42	p < .001

Table 4. Differences between experimental and control groups in attitudinal measures

Attitude level	Control group (n = 60): M (SD)	Experimental group (n = 60): M (SD)	t (118)	Significance
Pre-intervention	3.12 (.46)	3.14 (.51)	0.063	Not significant
Post-intervention	3.09 (.64)	3.34 (.44)	-2.12	p < .05

Hypothesis 2. Impact on Conceptual Understanding

To assess the effect of the intervention on students' understanding of alternative energy concepts, an independent samples t-test was again employed, comparing understanding levels between the groups before and after the intervention.

The analysis in **Table 3** indicates no significant difference in understanding prior to the intervention. However, after the instructional unit, the experimental group exhibited a significantly higher level of understanding than the control group ($t [58] = -3.42$, $p < .001$). These results confirm the second hypothesis, indicating that the use of experimental demonstrations in the teaching of alternative energy significantly enhances students' comprehension of the subject matter.

Hypothesis 3. Impact on Attitudes Toward Science

To determine the intervention's impact on students' attitudes toward science, particularly their openness to experimentation and inclusivity within scientific learning contexts, a third independent samples t-test was conducted.

Prior to the intervention, both groups exhibited comparable attitudes toward science, with no significant differences observed (**Table 4**). Following the intervention, however, students in the experimental group demonstrated significantly more positive attitudes toward science ($t [118] = -2.12$, $p < .05$). This supports the third hypothesis, indicating that experiential, demonstration-based teaching not only improves understanding and academic achievement but also fosters a more favorable disposition toward science learning.

The results of the three hypotheses confirm the overall effectiveness of the experimental demonstration method in enhancing student learning outcomes. Specifically, students exposed to demonstration-based instruction on alternative energy exhibited significantly greater academic achievement, higher levels of conceptual understanding, and more positive attitudes toward science compared to those taught through traditional methods. These outcomes suggest that integrating hands-on, visual, and inquiry-driven instructional strategies can produce substantial cognitive and affective gains in middle school science education. The intervention program demonstrated a statistically and educationally significant positive impact across all measured domains.

DISCUSSION

The purpose of this research was to investigate the impact of experimental demonstrations on the academic achievement, conceptual understanding, and attitudes toward science of third-grade students in the context of alternative energy education, encompassing solar, wind, hydropower, biomass, and geothermal energy. Conducted using a mixed-methods quasi-experimental design with 120 students from an Arab-community middle school, the study compared an experimental group that received demonstration-based instruction with a control group taught through traditional methods. The findings revealed that students exposed to experimental demonstrations showed significantly higher academic performance and a deeper understanding of scientific concepts than their peers in the control group. Additionally, these students developed more positive attitudes toward science, including increased enthusiasm, curiosity, and openness to inclusivity in scientific learning. The results highlight the effectiveness of hands-on, inquiry-driven teaching approaches in enhancing both cognitive and emotional engagement in science education, particularly in fostering scientific literacy and environmental awareness from an early age.

The results related to the first hypothesis, which tested whether students who learned about alternative energy through experimental demonstrations would achieve higher academic performance compared to those who learned through conventional methods, clearly indicated a significant positive effect of the intervention. Students in the experimental group demonstrated substantially higher academic achievement scores following the intervention. In contrast, no significant difference was observed between the two groups prior to the implementation of the demonstration-based instruction. These findings are highly consistent with a growing body of literature emphasizing the impact of experiential learning strategies in science education. For instance, Anzum et al. (2025) and Batni and Junaini (2025) found that hands-on demonstrations enhanced both students' grasp of scientific content and their performance on standardized assessments. Similarly, Clark (2025) and Cole et al. (2023) highlighted how experiential engagement with abstract scientific concepts, such as energy transformation, leads to measurable gains in cognitive processing and retention.

Furthermore, this study's results align with those of Shahid et al. (2019), who noted that physical demonstrations help scaffold complex content in accessible ways, mainly when learners are introduced to interdisciplinary themes such as sustainability or energy systems. However, the findings also introduce nuanced insight when contrasted with Kyere (2017) and Mayes and Myers (2015), who caution that without appropriate scaffolding, hands-on methods alone may not uniformly benefit all learners, especially those lacking prior foundational knowledge. Nonetheless, in this study, the intervention has been sufficiently structured to mitigate this concern, resulting in consistent academic gains. While the current findings do not contradict previous literature, it is worth noting that Miladinović (2025) raises critical concerns about the sustainability of demonstration-based gains over time, an aspect this study does not directly address. However, it raises questions for further inquiry.

The second hypothesis examined whether students exposed to experimental demonstrations would demonstrate higher levels of conceptual understanding of alternative energy compared to those receiving conventional instruction. The statistical analysis revealed a significant improvement in understanding among students in the experimental group, while no such change occurred in the control group. This result receives strong support from the existing literature, particularly studies by Altun and Ozsevgec (2025) and Larassati et al. (2025), which argue that the visualization and physical manipulation of scientific phenomena significantly enhance students' comprehension of these phenomena. According to Shahid et al. (2019), such methods facilitate sensory learning, which is crucial for abstract concepts such as energy transfer and conservation. The current findings also align with the work of Papilaya and Tuapattinaya (2022), who emphasized the role of contextualized demonstration in making scientific content meaningful and relevant to students' lives, thereby reinforcing understanding. Moreover, King et al. (2015) and Pambudi et al. (2025) argue that experimental presentations often activate prior knowledge and stimulate mental models, making new information easier to assimilate. In this study, the use of real-world examples, such as solar panels and wind turbines, likely supported these cognitive processes. Conversely, a point of tension arises when these findings are considered alongside research by Mayes and Myers (2015), who argue that some demonstrations can lead to a superficial understanding if not accompanied by guided inquiry or reflective discussion. However, the improved understanding scores in this study suggest that the instructional delivery included these reflective components. Additionally, while Solihat et al. (2024) emphasize the importance of inquiry-driven dialogue accompanying demonstrations to avoid misinterpretation, the study's outcomes suggest that the integration of experimental demonstrations in this case was sufficiently rich to foster deep comprehension. Therefore, the results provide robust evidence for the positive impact of demonstration-based instruction on scientific understanding, supporting and extending the broader discourse in science education.

The third hypothesis proposed that students who learned through experimental demonstrations would exhibit more positive attitudes toward science than their peers in the control group. Post-intervention data confirmed this hypothesis, revealing that the experimental group reported significantly higher attitudinal scores. These findings are corroborated by a wealth of existing research emphasizing the affective benefits of experiential learning. For example, Bai et al. (2016) and Alfiah et al. (2025) found that hands-on activities foster enthusiasm, curiosity, and a sense of ownership over learning, all of which positively influence students' attitudes toward science. The findings are also congruent with those of Haynes et al. (2024), who assert that positive affective responses in the classroom are key indicators of student engagement and long-term interest in science-related subjects.

Furthermore, Assaf (2018) highlights the transformative power of experiential science learning in shaping inclusive and gender-sensitive attitudes, particularly among underrepresented student groups–a theme echoed in this study's emphasis on attitudes toward women in science. The enhanced attitudes observed in the current study may also reflect what Cole et al. (2023) describe as the motivational impact of observable, meaningful outcomes in the learning process. When students see how science connects to real life, their emotional investment in the subject grows. On the other hand, some contrasting perspectives in the literature warrant consideration. Russ and Turnbull (2025), for example, caution that affective gains from experimental learning may be short-lived if not embedded in broader pedagogical practices that support long-term identity development in science. Similarly, Solihat et al. (2024) argue that without sustained teacher enthusiasm and institutional support, initial motivational surges may wane over time. Although the present study did not include a longitudinal component to address this potential decline, its findings nonetheless suggest that the immediate emotional and attitudinal impact of demonstration-based instruction is substantial and meaningful. Moreover, the results resonate with the broader theoretical framework articulated by Namdar and Shen (2018), who propose that affective engagement is both a precondition and an outcome of effective science learning. Thus, this study reinforces the assertion that demonstration-based science instruction not only enhances cognitive outcomes but also fosters a more inclusive and enthusiastic classroom culture.

In summary, the discussion of all three hypotheses reveals a pattern of findings that is broadly consistent with, and often strongly supported by, recent empirical and theoretical literature in science education. The experimental demonstrations had a positive influence on students' academic performance, deepened their understanding of complex energy systems, and enhanced their attitudes toward science and scientific inquiry. While minor contradictions in the literature highlight the importance of pedagogical nuance and the potential variability of outcomes depending on the instructional context, the present study confirms the pedagogical value of demonstration-based teaching as a multifaceted tool for advancing both cognitive and affective learning in science classrooms.

CONCLUSIONS

This study examined the impact of experimental demonstrations on the academic achievement, conceptual understanding, and attitudes of third-grade students toward science, with a focus on alternative energy sources, including solar, wind, hydropower, biomass, and geothermal energy. Conducted in an Arab-community middle school using a mixed-methods quasi-experimental design, the research compared a control group receiving traditional instruction with an experimental group exposed to hands-on, demonstration-based teaching. Quantitative data were gathered through academic tests and attitude questionnaires, while qualitative insights were drawn from student interviews. Findings indicated statistically significant gains in academic performance, deeper conceptual understanding, and more positive attitudes toward science among students who experienced the demonstration-based instruction. The results suggest that active, sensory-rich, and contextually grounded teaching methods are highly effective in making complex scientific concepts accessible and engaging for young learners, mainly when linked to real-world issues such as sustainability and renewable energy.

The study concludes that experimental demonstrations have a significant impact on academic outcomes in science education. The experimental group outperformed the control group across all key metrics: academic achievement, understanding of alternative energy concepts, and attitudes toward science. These findings align with a growing body of literature that emphasizes the cognitive and emotional benefits of experiential learning, particularly in science subjects often perceived as abstract or challenging. The study further affirms that hands-on, demonstration-based teaching promotes not only better knowledge retention but also emotional engagement and positive student-teacher interactions. The improvement in attitudes toward science, including increased interest and more inclusive views about roles in scientific fields, underscores the broader educational value of such methods. Demonstrations helped create an active and inclusive classroom culture, where students felt more invested in learning, which in turn reinforced their motivation and comprehension. This approach is particularly relevant in light of the pressing global need for environmental awareness and scientific literacy.

Furthermore, this research highlights the importance of collaboration across various disciplines in promoting a more comprehensive and practical approach to science education. The multidisciplinary nature of alternative energy topics, which encompass environmental ethics, the history of technology, mathematical modeling, and mental engagement, necessitates the collective efforts of scientists, educators, mathematicians, historians, philosophers, cognitive psychologists, sociologists, and other relevant disciplines. Contributions from these diverse domains should be actively included in planning new research projects or designing curricula, ensuring that teaching frameworks are well-informed scientifically, grounded in history and philosophy, and developmentally appropriate for students. Such collaboration could enhance educational possibilities and help integrate social responsiveness into science education, encouraging more coherence between disciplines.

Despite the positive outcomes, several limitations should be acknowledged. First, the study was limited to a single geographic and cultural context, involving students from a single school in the Arab community, which may limit the generalizability of the findings. Second, the intervention lasted only one and a half months, leaving open questions about the long-term retention of knowledge and the sustainability of attitudinal changes. Third, the study focused primarily on alternative energy content and did not examine whether similar results would occur across other science topics. Furthermore, while qualitative data provided insight into students' perceptions, teacher perspectives, and classroom observation data were not included, potentially overlooking implementation challenges or instructional nuances. Future research should expand to diverse educational settings and populations, explore the long-term impact of demonstration-based teaching, and investigate how this approach interacts with other pedagogical strategies. Including longitudinal studies and teacher-focused data could provide a more comprehensive picture of how demonstration-based instruction affects educational outcomes over time and across various contexts.

Based on the study's findings, educators and curriculum developers are encouraged to incorporate experimental demonstrations into science instruction, mainly when teaching complex or abstract topics, such as energy systems. Schools should invest in low-cost, scalable materials for classroom demonstrations to make science more accessible, especially in under-resourced environments. Teacher training programs should include modules on designing and implementing practical, inquiry-driven demonstrations that are visually engaging and contextually relevant. Demonstrations should be accompanied by reflective discussion and guided inquiry to deepen understanding and prevent misconceptions. Educational policymakers should consider revising science curricula to emphasize experiential learning, integrating environmental topics such as renewable energy from an early age. Additionally, classroom environments should foster collaboration and inclusivity, utilizing hands-on activities to bridge gaps in gender and learning styles. Overall, the study supports a shift toward more dynamic, student-centered approaches in science education that not only enhance academic achievement but also foster curiosity and responsible citizenship in an era of environmental urgency.

Author contributions: MH: supervision, conceptualization, project administration, writing – original draft; **ML:** data curation, writing – original draft; **SA:** formal analysis, writing – original draft. All authors approved the final version of the article.

Funding: This article was supported by the Israeli Ministry of Energy and Infrastructure under grant 222-11-093.

Acknowledgments: The authors would like to thank the Israeli Ministry of Energy and Infrastructure for their valuable support.

Ethics declaration: This study was conducted in accordance with the ethical standards of the institutional and national research committees. Participation was voluntary, and informed consent was obtained from all participants and their guardians before data collection. No identifying information was collected, and all responses were kept strictly confidential.

Declaration of interest: The authors declared no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

REFERENCES

Agustian, H. Y. (2025). Demonstrations as a part of inquiry-based teaching in science teacher education. *Science Teacher Education Hub, 2025*, 7-19. https://researchprofiles.ku.dk/en/publications/demonstrations-as-a-part-of-inquiry-based-teaching-in-science-tea/

Alfiah, M. H., Bramastia, & Sukarmin. (2025). Literature review: The impact of project-based learning on scientific literacy in secondary education. *Jurnal Penelitian Pendidikan IPA, 11*(1), 1-9. https://jppipa.unram.ac.id/index.php/jppipa/article/view/8616

Altun, E., & Ozsevgec, T. (2025). Making argumentation-based learning and teaching happen: Exploring the development of preservice science teachers' argumentation competencies. *Science & Education*. https://doi.org/10.1007/s11191-024-00612-1

Anzum, A., Rana, M. J., Ahmed, E., & Rahman, S. (2025). Determining the optimal window size and orientation of an academic building in a subtropical climate. *International Journal of Building Pathology and Adaptation*. https://doi.org/10.1108/IJBPA-11-2024-0232

Aramo-Immonen, H. (2013). Mixed methods research design. In M. D. Lytras, D. Ruan, R. D. Tennyson, P. Ordonez De Pablos, F. J. García Peñalvo, & L. Rusu (Eds.), *Information systems, e-learning, and knowledge management research. WSKS 2011. Communications in computer and information science, vol 278* (pp. 32-43). Springer. https://doi.org/10.1007/978-3-642-35879-1_5

Assaf, J. (2018). *Integrated solar-hydrogen combined heat and power/solar-thermal systems for power and hot water supply in standalone applications* [PhD dissertation, RMIT University].

Astuti, D. (2023). The effectiveness of using conceptual instruction (ICI) approach toward the concept mastery based on classroom activity and learning style. In *Proceedings of the International Conference on Religion, Science and Education* (pp. 105-116). https://sunankalijaga.org/prosiding/index.php/icrse/article/view/898

Awwalina, D. P., Dawana, I. R., Dwikoranto, D., & Rizki, I. A. (2025). Effectivity of STEAM education in physics learning and impact to support SDGs. *Journal of Current Studies in SDGs, 1*(1), 1-19. https://doi.org/10.63230/jocsis.1.1.8

Bai, H., Aman, A., Xu, Y., Orlovskaya, N., & Zhou, M. (2016). Effects of web-based interactive modules on engineering students' learning motivations. *American Journal of Engineering Education, 7*(2), 83-96. https://doi.org/10.19030/ajee.v7i2.9840

Basheer, A., Hugerat, M., Kortam, N., & Hofstein, A. (2016). The effectiveness of teachers' use of demonstrations for enhancing students' understanding of and attitudes to learning the oxidation-reduction concept. *Eurasia Journal of Mathematics, Science and Technology Education, 13*(3), 555-570. https://doi.org/10.12973/eurasia.2017.00632a

Batni, B., & Junaini, S. N. (2025). Redefining computational thinking: Synergizing unplugged activities with block-based programming. *Education and Information Technologies, 30*(2), 2361-2388. https://doi.org/10.1007/s10639-024-12869-8

Clark, Q. M. (2025). A pedagogical approach: Toward leveraging mathematical modeling and AI to support integrating humanities into STEM education. *Frontiers in Education, 9*. https://doi.org/10.3389/feduc.2024.1396104

Cleopas, B. C., & Igbojinwaekwu, P. C. (2024). Demonstration and discussion teaching methods on attitude and retention of urban and rural students in senior school biology in Yenagoa and Ogbia local government areas of Bayelsa State. *Contemporary Research in Education and English Language Teaching, 6*(1), 50-61. https://doi.org/10.55214/26410230.v6i1.1132

Cole, L. B., Fallahhosseini, S., Zangori, L., & Oertli, R. T. (2023). Learnscapes for renewable energy education: An exploration of elementary student understanding of solar energy systems. *Interdisciplinary Journal of Environmental and Science Education, 19*(1), Article e2305. https://doi.org/10.29333/ijese/13034

Doyle, L., Brady, A. M., & Byrne, G. (2016). An overview of mixed methods research–Revisited. *Journal of Research in Nursing, 21*(8), 623-635. https://doi.org/10.1177/1744987116674257

Flener Lovitt, C. E., Bertram, M., Campbell, D., Cook Shinneman, A., Groom, M., Hathaway, D., Lambert, A., & Lasker, G. A. (2025). Embodying change: Courses that integrate narrative, storytelling, and embodied learning in climate change education. *Journal of Chemical Education, 102*(2), 516-526. https://doi.org/10.1021/acs.jchemed.4c00465

Frimpong, B. A., Kukah, A. S. K., Blay, A. V. K. J., Anafo, A., Kukah, R. M. K., Wellington, S. N. O., & Kuutiero, D. N. (2025). Strategies to enhance energy sustainability in line with sustainable development goal (SDG) 7 (affordable and clean energy): Case of Ghana. *International Journal of Energy Sector Management, 19*(2), 477-496. https://doi.org/10.1108/IJESM-05-2024-0005

Haynes, J. C., Anderson, R., Byrd, A. P., & McCubbins, O. P. (2024). Determining the teaching resources needed for an ideal post-secondary applied STEM (agricultural mechanics) learning laboratory: A Delphi approach. *CTE Journal, 12*(1), Article 18. https://www.thectejournal.com/uploads/1/0/6/8/10686931/haynes_summer_2024.pdf

Henderson, S., Tomas, L., & King, D. (2025). Does topic matter? Investigating students' interest, emotions and learning when writing stories about socioscientific issues. *Research in Science Education*. https://doi.org/10.1007/s11165-025-10239-z

Isham, A., Jefferies, L., Blackburn, J., Fisher, Z., & Kemp, A. (2025). Green healing: Ecotherapy as a transformative model of health and social care. *Current Opinion in Psychology, 62*, Article 102005. https://doi.org/10.1016/j.copsyc.2025.102005

Khan, K. A., Ahmad, W., Zubair, A. O., Subhan, M., & Shah, M. I. (2025). From invention to progress: Energy technology innovation and sustainable development in OECD economies. *PLoS ONE, 20*(2), Article e0310104. https://doi.org/10.1371/journal.pone.0310104

King, D., Ritchie, S., Sandhu, M., & Henderson, S. (2015). Emotionally intense science activities. *International Journal of Science Education, 37*(12), 1886-1914. https://doi.org/10.1080/09500693.2015.1055850

Kotsis, K. T. (2024). Promoting scientific literacy by teaching in primary education the issue of "biomass for biodiesel". *European Journal of Contemporary Education and E-Learning, 2*(5), 63-76. https://doi.org/10.59324/ejceel.2024.2(5).04

Kyere, J. (2017). *The effectiveness of hands-on pedagogy in STEM education* [PhD dissertation, Walden University].

Larassati, A. S. A., Suciati, S., Sari, M. W., Silvita, S., Prasetyo, O., & Rachman, H. T. (2025). Identification of scientific knowledge of the Patehan tradition of Yogyakarta Palace as a source of natural science learning. *Jurnal Pendidikan Sains Indonesia, 13*(1), 213-232. https://doi.org/10.24815/jpsi.v13i1.42319

Mayes, R., & Myers, J. (2015). *Quantitative reasoning in the context of energy and environment: Modeling problems in the real world*. Springer. https://doi.org/10.1007/978-94-6209-527-4

Miladinović, S. M. (2025). Green analytical chemistry: Integrating sustainability into undergraduate education. *Analytical and Bioanalytical Chemistry, 417*(4), 665-673. https://doi.org/10.1007/s00216-024-05680-4

Mulyani, H., Zulkarnaen, R. H., & Hernisa, Y. (2025). The profile analysis of prospective elementary teachers' scientific literacy as an initial strategy to conduct science courses. *Jurnal Penelitian Pendidikan IPA, 11*(1), 1215-1223. https://jppipa.unram.ac.id/index.php/jppipa/article/view/9822

Namdar, B., & Shen, J. (2018). Knowledge organization through multiple representations in a computer-supported collaborative learning environment. *Interactive Learning Environments, 26*(5), 638-653. https://doi.org/10.1080/10494820.2017.1376337

Nikitin, A., Kácovský, P., Snětinová, M., Chvál, M., Houfková, J., & Koupilová, Z. (2025). Physics demonstrations, science show, or hands-on practical work? Exploring students' intrinsic motivation. *Physical Review Physics Education Research, 21*, Article 010146. https://doi.org/10.1103/physrevphyseducres.21.010146

Oliveira, H., & Bonito, J. (2023). Practical work in science education: A systematic literature review. *Frontiers in Education, 8*. https://doi.org/10.3389/feduc.2023.1151641

Omagwa, K. E. (2022). *Influence of practical approaches of teaching agriculture on academic performance in high schools in Kisii County, Kenya* [PhD dissertation, Kisii University].

Palines, K. M. E., Moreno, J. M. U., Tatlonghari, A. G., & Ortega-Dela Cruz, R. (2025). Integrating information and communication technologies to enhance high school students' research capabilities. *Journal of Educational Research and Practice, 15*(1), Article 6. https://doi.org/10.5590/JERAP.2025.15.1952

Pambudi, N. A., Nasrulloh, A. F., Biddinika, M. K., Chapman, A. J., & Huat, B. S. L. (2025). Trade-offs between energy, the economy, amenity, and education: Findings from Indonesia. *International Journal of Global Energy Issues, 47*(1-2), 150-172. https://doi.org/10.2139/ssrn.4509312

Papilaya, P. M., & Tuapattinaya, P. M. J. (2022). Problem-based learning dan creative thinking skills students based on local wisdom in Maluku. *Al-Ishlah: Jurnal Pendidikan, 14*(1), 429-444. https://doi.org/10.35445/alishlah.v14i1.1406

Prajapati, S. (2025). Advancing science education: A comprehensive review of pedagogical innovations from 2010-2023. *Asian Journal of Applied Science and Technology, 9*(1), 89-106. https://doi.org/10.38177/ajast.2025.9109

Ramadani, F. (2024). The role of demonstrations in the teaching and learning of physics in primary schools in Kosovo. *Scientific Bulletin, 37*, 40-50. https://unkorce.edu.al/wp-content/uploads/2025/03/Buletini-Shkencor-nr.-37-SSHZ-41-51.pdf

Reed, S. S., Mullen, C. A., & Boyles, E. T. (2021). *Problem-based learning in elementary school. What strategies help elementary students develop?* Springer. https://doi.org/10.1007/978-3-030-70598-5

Russ, D., & Turnbull, T. (2025). *Energy's history: Toward a global canon*. Stanford University Press. https://doi.org/10.1515/9781503641518

Sapochetti, L. (2025). *The good energy: Community, ethics, and the economy in an Italian electricity cooperative* [PhD dissertation, The University of St Andrews]. https://doi.org/10.17630/sta/1203

Schoonenboom, J., & Johnson, R. B. (2017). How to construct a mixed methods research design. *Kolner Zeitschrift fur Soziologie und Sozialpsychologie, 69*(Suppl 2), 107-131. https://doi.org/10.1007/s11577-017-0454-1

Shahid, F., Aleem, M., Islam, M. A., Iqbal, M. A., & Yousaf, M. M. (2019). A review of technological tools in teaching and learning computer science. *Eurasia Journal of Mathematics, Science and Technology Education, 15*(11), Article em1773. https://doi.org/10.29333/ejmste/109611

Solihat, R., Haqiqi, B. Y., & Widodo, A. (2024). Waste to energy: A STEM-ESD approach to improve student awareness and action in converting waste into eco-friendly energy. *Jurnal Pendidikan Biologi Indonesia, 10*(3), 117-134. https://doi.org/10.22219/jpbi.v10i3.34330

Urdanivia Alarcón, D. A., Talavera-Mendoza, F., Rucano Paucar, F. H., Cayani Caceres, K. S., & Machaca Viza, R. (2023). Science and inquiry-based teaching and learning: A systematic review. *Frontiers in Education, 8*. https://doi.org/10.3389/feduc.2023.1170487

Wörner, S., Kuhn, J., & Scheiter, K. (2022). The best of two worlds: A systematic review on combining real and virtual experiments in science education. *Review of Educational Research, 92*(6), 911-952. https://doi.org/10.3102/00346543221079417