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Research paper

Recycling and Upcycling through Integrated STEM Project-Based Learning in an Arabic-Speaking Primary School in Israel

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ABSTRACT

This two-class quasi-experimental pilot documented class-level score patterns before and immediately after a four-week recycling and upcycling STEM-PBL unit in three self-reported components of environmental literacy among fourth-grade students in an Arabic-speaking school in northern Israel. Two intact classes (N = 62), with one class per condition, received either STEM-PBL instruction (n = 32) or teacher-led comparison instruction (n = 30). The intervention, conducted during regular science lessons, engaged small groups in relevant design challenges integrating measurement, materials, tool use, and engineering constraints. STEM was treated as an instructional design approach rather than an achievement outcome, and implementation fidelity was not independently assessed. Outcomes were measured using an age-appropriate three-point questionnaire assessing positive environmental behavioral tendencies, awareness and perceived knowledge, and negative environmental behavioral tendencies. Because the same students completed pre- and post-unit questionnaires, but anonymous responses could not be linked, observations were repeated but unpaired; therefore, inferential pre-posttests and standardized effect-size estimates were not used. Descriptively, the experimental class showed more favorable post-unit means and larger raw mean differences than the comparison class across all three outcomes. These patterns do not establish individual change, causal effectiveness, or improvement in environmental literacy as a whole. Interpretation is further limited by one class per condition, immediate self-report measurement, marked ceiling and floor effects, possible content overlap and demand characteristics, and lack of fidelity evidence. The unit should therefore be viewed as a documented instructional example warranting replication across classrooms with delayed assessments, objective knowledge measures, behavioral indicators, and implementation-fidelity measures.

Keywords: integrated STEM, STEM-PBL, environmental literacy, recycling and upcycling, primary education, sustainability education

Environmental literacy (EL) is one of the primary goals of environmental education. It encompasses the acquisition of knowledge, dispositions, practices, and behaviors related to social-ecological systems, including understanding environmental processes and issues, human-environment interactions, environmental identity, and self-efficacy (Hunter & Jordan, 2022). Amid the escalating global environmental crisis driven largely by human activity, developing EL from an early age has become increasingly important for safeguarding current and future well-being (Biber et al., 2023; Palombo, 2021). Against the backdrop of escalating environmental challenges in Israel and persistent environmental inequities affecting Arab communities, strengthening sustainability-oriented competencies in primary education is both timely and necessary (Hayik, 2021; Negev & Garb, 2014). However,

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EL cannot be reduced to knowledge alone. Theories have emphasized that an environmentally literate individual should not only possess environmental understanding and pro-environmental dispositions but also engage in environmentally sustainable behaviors (Kabylbek et al., 2025; Svobodová & Kroufek, 2022). This translation from knowing to doing remains a persistent challenge in school-based environmental education, where awareness or concern may not reliably yield consistent pro-environmental action (Djordjevic et al., 2026; Goldman et al., 2018; Klein et al., 2021).

Although integrated STEM-PBL has received growing attention, empirical evidence regarding its use for sustainability-oriented learning in primary classrooms remains limited and context-dependent (Wan et al., 2023; Winarni et al., 2022). In this study, STEM-PBL was conceptualized as an integrated design process in which the students defined a sustainability problem, worked under explicit constraints, generated and tested design ideas, and used simple measurements, materials, and tools to iteratively improve a tangible solution. The literature has also shown that EL is often poorly integrated across school curricula and tends to remain confined to science topics with little emphasis on experiential inquiry-based learning (Kaya & Elster, 2019).

In a study of Israeli primary school students, Goldman et al. (2018) found that environmental concerns did not consistently translate into action, but that project-based approaches gave the students an opportunity to apply sustainability concepts through hands-on activities and student-led initiatives. The current study focused on an Arab school context in Israel, where environmental education opportunities may be shaped by uneven infrastructure, locally available resources, and broader contextual constraints (Hayik, 2021; Negev & Garb, 2014). The importance of contextual resources is also illustrated by Katz's (2026) qualitative study of Arab higher-education students in Israel, whose accounts identified unreliable connectivity and unsuitable home study conditions as barriers to remote learning.

Although integrated STEM-PBL has been examined in primary education, the literature reviewed here provides limited evidence on short units implemented within regular science timetables that combine recycling and upcycling design activities using readily available materials with questionnaire-based environmental outcomes. Evidence is particularly limited in Arabic-speaking primary-school contexts in Israel. In these contexts, environmental learning opportunities may be shaped by local infrastructure and available resources (Hayik, 2021; Negev & Garb, 2014). The present study therefore documents one classroom enactment of an approximately four-week integrated STEM-PBL unit and reports class-level score distributions across two measurement occasions. Its contribution is implementation-oriented: it makes visible how a sustainability topic was organized within regular science lessons through collaborative design challenges, ordinary reusable materials, basic measurement, tool use, engineering constraints, iterative refinement, and communication. The accompanying score summaries provide descriptive context for that enactment. They are not used to estimate the effect of the unit, establish improvement, or support a claim of general efficacy, and STEM achievement was not assessed.

RESEARCH BACKGROUND

Environmental literacy (EL)

Escalating environmental challenges underscore the educational need to cultivate EL (Maurer & Bogner, 2020). Contemporary conceptualizations emphasize that environmental literacy is not limited to awareness; it is a multidimensional construct that integrates cognitive, affective, and behavioral/action components (Kaya & Elster, 2019; Winarni et al., 2022). For these reasons, school-based EL needs to encourage students not only to acquire knowledge but also to develop skills to interpret environmental information, evaluate evidence, and make responsible decisions aligned with sustainability (Kaya & Elster, 2019).

Many environmental topics (e.g., climate change, biodiversity loss, and pollution) require reasoning with evidence, the consideration of trade-offs and values, and the ability to translate understanding into action within everyday contexts. Primary school instructional approaches therefore need to bridge the "mind-the-gap" problem between students' environmental concerns and their actual pro-environmental practices, whereby knowledge or concern does not automatically translate into behavioral change (Kollmuss & Agyeman, 2002).

Teachers play a central role in cultivating environmental attitudes and a sense of accountability, which enable learners to act to maintain, restore, and enhance ecological stability (Artvinli & Demir, 2018; Liobikienė & Poškus, 2019; Winarni et al., 2022). At the curriculum level, studies have called for inquiry-oriented and interdisciplinary environmental education that better prepares students for future challenges, while emphasizing the need for more empirical studies that examine both teachers' and students' perspectives in such implementations (Hokayem & Jin, 2019; Kidman & Casinader, 2019).

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STEM education combined with project-based learning (STEM-PBL)

STEM education integrates science, technology, engineering, and mathematics through interdisciplinary learning that connects school knowledge to real-world applications and problem solving (Siew & Ambo, 2018). Internationally, STEM has been positioned as a response to fragmented knowledge by promoting integrated understanding and application (Millar, 2020). Recent work stresses that high-quality integrated STEM should move beyond isolated subjects and be intentionally designed around authentic problems and integration structures that often require structured design processes and collaboration among multidisciplinary teacher teams (De Meester et al., 2021).

Project-based learning (PBL) is a learner-centered pedagogy in which students collaboratively investigate complex questions over time and produce meaningful products (Almulla, 2020). PBL has been associated with gains in engagement, motivation, interdisciplinary understanding, and transferable competencies such as critical thinking, creativity, communication, and collaboration (Baran et al., 2021; Bicer et al., 2025). Because PBL emphasizes sustained inquiry and project creation, it aligns naturally with integrated STEM, particularly through engineering design and applied problem solving (Slough & Milam, 2013; Tseng et al., 2013).

STEM-PBL is commonly described as an open-ended, inquiry-driven approach that integrates STEM disciplines through tasks requiring students to explore questions, solve problems, and design solutions, grounded in constructivist and situated learning perspectives (Wan et al., 2023). STEM-PBL provides a coherent framework in which students address authentic problems from scientific and engineering perspectives and develop responsibility through collaborative solution design (Capraro et al., 2013). Accordingly, in the current study, STEM was treated as an instructional process embedded in the intervention (integrated design-cycle enactment) rather than as an outcome measure of STEM achievement.

Empirical work links STEM-PBL to improved motivation, engagement, and problem-solving, as well as to outcomes such as spatial/geographic skills and science identity (Han et al., 2015). However, successful implementation often depends on teacher preparedness and classroom conditions since teachers may face challenges related to interdisciplinary planning, time constraints, and classroom management, and students' readiness can influence engagement and learning equity (Han et al., 2015). These boundary conditions may help explain why STEM-PBL effects can vary across settings and outcomes, particularly when scaffolding, time for iteration, or classroom routines are insufficient. Sustained professional development and ongoing support have been emphasized as enabling conditions for classroom enactment (DeJarnette, 2018). Within teacher education for multilingual classrooms, Halpern et al. (2025) similarly emphasize sustained guidance and critical reflection to help prospective teachers translate awareness of learners' cultural and linguistic backgrounds into instructional practice.

The potential of STEM-PBL to promote environmental literacy

Despite its promise, evidence on STEM-PBL is not uniformly positive, and outcomes appear to depend on implementation conditions. In the present study, environmental literacy was operationalized through three questionnaire-based, self-reported components: positive environmental behavioral tendencies, environmental awareness and perceived knowledge, and negative environmental behavioral tendencies. Accordingly, the three subscales are interpreted as environmental-literacy-related self-reports concerning perceived awareness and behavioral tendencies rather than as a comprehensive measure of environmental literacy; no objective knowledge test, direct behavioral observation, or performance-based assessment was administered. Prior research suggests that STEM-PBL may support engagement and higher-order thinking, although short-term outcomes may vary across measures and may not persist over time.

The present study focused on an Arabic-speaking primary school in Israel, an underrepresented context in the STEM education literature. STEM was treated as an instructional process rather than as a measured outcome. Students planned, constructed, refined, and communicated recycling and upcycling artifacts using measurement, materials, tools, and design constraints. The study therefore examined short-term, self-reported environmental literacy components rather than STEM achievement.

Specifically, the study explored class-level score patterns before and after participation in a recycling- and upcycling-centered STEM-PBL unit across three questionnaire-based, self-reported environmental literacy components. The instructional contribution lies in documenting how the sustainability theme was translated into five group design challenges and a shared sequence of problem framing, planning, material selection, construction, refinement, reflection, and communication. Across the projects, STEM integration was enacted through different combinations of measurement, materials, purposeful tool use, design constraints, construction, and communication. This documentation allows the unit to be considered as a feasible classroom configuration under the reported conditions rather than as a tested causal model. The questionnaire results are therefore treated as occasion-specific descriptions of the two participating classes and not as validation of the unit's effectiveness.

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RATIONALE AND QUESTIONS

Despite the prominence of EL as a central aim of environmental education, school-based initiatives continue to face a knowing-to-doing gap, whereby awareness or concern does not necessarily translate into sustained action (Goldman et al., 2018; Klein et al., 2021). Integrated STEM-PBL may connect sustainability content with authentic design activity, but evidence from short, timetable-aligned primary-school interventions remains limited and context-dependent. Recent studies illustrate STEM-PBL and knowledge–action applications across varied educational and technological settings (Kaya & Elster, 2019; Yang et al., 2025), but they do not establish uniform effects in primary classrooms. Within the Israeli context, research has documented challenges related to environmental learning and infrastructure in Arab communities (Hayik, 2021; Negev & Garb, 2014).To address this gap, the present two-class quasi-experimental pilot documented one approximately four-week classroom implementation of a recycling and upcycling STEM-PBL unit and described the score patterns observed in the two participating classes. The study focused on three questionnaire-based, self-reported outcomes: positive environmental behavioral tendencies, environmental awareness and perceived knowledge, and negative environmental behavioral tendencies. Because one intact class represented each condition and the anonymous pre- and post-test questionnaires could not be linked at the individual level, the analytical questions were deliberately limited to baseline description and comparative class-level patterns across the two occasions. The study was not designed to estimate individual change, causal intervention effects, or subgroup-specific change

Research questions

RQ1. What were the baseline levels of the three measured self-reported environmental literacy components among the participating primary school students: (a) positive environmental behavioral tendencies, (b) environmental awareness and perceived knowledge, and (c) negative environmental behavioral tendencies?

RQ2. How did the raw pre-test-to-post-test mean differences in the three measured components compare between the experimental and comparison classes?

METHODOLOGY

Research design

A quantitative two-class quasi-experimental pretest–posttest pilot design was implemented using two intact fourth-grade classes. One class participated in the STEM-PBL condition, whereas the other followed the regular teacher-led curriculum. Both classes covered the same environmental topic, were taught by the same science teacher over the same approximately four-week period, received equivalent total scheduled instructional time, and completed identical pre- and post-questionnaires under the same administration procedures. The comparison class received textbook-based explanations, guided whole-class discussions, worksheet practice, and individual and whole-class learning activities but did not participate in small-group design, artifact construction, iterative refinement, gallery-walk presentations, or public sharing. To reduce possible contamination, the classes were taught during separate class periods using condition-specific materials, and STEM-PBL resources were provided only to the experimental class.

With one intact class per condition, instructional condition and class were fully confounded, and student-level observations did not provide independent class-level replication. The design therefore cannot distinguish intervention-related differences from those arising from pre-existing class characteristics or other unmeasured class-level factors. All comparisons are interpreted solely as descriptive patterns in the two participating classes and do not support population-level generalization or causal inference.

Participants

The sample comprised 62 fourth-grade students from two intact classes in an Arabic-speaking primary school in Israel's Northern District (M age = 8.75 years). One class served as the experimental class (n = 32), and the other served as the comparison class (n = 30). The participating school and the two intact fourth-grade classes were selected through convenience sampling based on accessibility and willingness to participate. After the two classes had been identified, they were randomly assigned at the class level to the experimental and comparison conditions before data collection. This approach preserved the existing classroom structure and minimized disruption to the regular school timetable. No standardized measure of students' socioeconomic background was collected.

Both classes were taught by the same science teacher, who had 12 years of teaching experience and held a master's degree in science education. The school had not previously implemented student-centered environmental projects of the type used in the present intervention. Before the intervention, the teacher received structured guidance from the researcher regarding the study objectives, the instructional sequence, and the core components

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of the STEM-PBL unit. Ongoing support was also provided during implementation. This form of guidance is consistent with recommendations emphasizing the importance of teacher preparation and support in STEM curriculum implementation (DeJarnette, 2018).

Research Tools

A 44-item questionnaire was adapted primarily from the environmental attitude scale developed for primary-school students by Artvinli and Demir (2018) and translated into Arabic for the present study. The adaptation also drew on established approaches to assessing children's environmental attitudes and knowledge through age-appropriate survey instruments (Leeming et al., 1995) and on questionnaire formats used in primary-level sustainability education research (Ruiz Vicente et al., 2020). Artvinli and Demir (2018) served as the principal source for the instrument, whereas Leeming et al. (1995) and Ruiz Vicente et al. (2020) informed the age-appropriate wording and questionnaire format.

The resulting instrument assessed three questionnaire-based, self-reported environmental-literacy-related components rather than environmental literacy as a comprehensive construct. It measured students' reported behavioral tendencies and perceived awareness and knowledge; it did not objectively test environmental knowledge or directly observe environmental behavior.

The questionnaire consisted of two parts. The first collected demographic information on gender. The second included environmental literacy items rated on a three-point Likert-type scale: 1 = disagree, 2 = somewhat agree, and 3 = agree. The three-point response format was selected to enhance clarity and reduce response burden for fourth-grade students.

The instrument comprised three subscales: self-reported positive environmental behavioral tendencies (28 items), environmental awareness and perceived knowledge (10 items), and self-reported negative environmental behavioral tendencies (6 items). The awareness and perceived knowledge subscale measured students' agreement with statements concerning their perceived awareness and understanding of environmental issues; it was not an objective knowledge test.

Representative items included "I turn off lights that have been left on" for self-reported positive environmental behavioral tendencies, "I know which items can be recycled in my local community" for environmental awareness and perceived knowledge, and "Protecting the environment is not my responsibility" for self-reported negative environmental behavioral tendencies. A mean score was calculated for each subscale by averaging the corresponding item scores, resulting in a possible range from 1 to 3. No items were reverse-coded. Higher scores on the positive behavioral tendencies and awareness and perceived knowledge subscales indicated more favorable self-reports. The negative-tendency items were retained in their original direction, such that higher scores indicated stronger endorsement of environmentally undesirable tendencies and therefore less favorable self-reports. Accordingly, the two behavior-related subscale scores were interpreted as self-reported behavioral tendencies rather than as direct observations of environmental behavior. A complete bilingual version of the questionnaire, including the demographic items, original Arabic statements, English translations, response options, item-to-subscale assignments, and scoring instructions, is provided as Supplementary File 1.

Language Adaptation and Preliminary Content Review

The questionnaire items were originally available in English and were translated into Arabic for administration. The Arabic version was independently back-translated into English, and the original and back-translated versions were compared to identify and resolve discrepancies in wording and meaning. Before administration, the Arabic version was also reviewed by two Arabic-speaking primary science teachers to evaluate linguistic clarity, comprehensibility, grade-level appropriateness for fourth-grade students, and consistency with the intended constructs. Minor wording adjustments were made where necessary without altering the intended meaning of the items.

Internal consistency was examined separately for each subscale using the pre-test data. Cronbach's alpha was .93 for self-reported positive environmental behavioral tendencies, .81 for environmental awareness and perceived knowledge, and .87 for self-reported negative environmental behavioral tendencies. These coefficients indicated good-to-excellent internal consistency for the three subscales in the present sample. Item-total correlations and factor analyses were not conducted because of the small sample. Accordingly, the alpha coefficients support only the internal consistency of the subscale scores in this sample; they do not establish construct validity, measurement invariance across occasions, or equivalence between the Arabic translation and the original instrument.

Intervention procedure

The intervention was implemented during regular science lessons over approximately four weeks and comprised 12 lessons of 45 minutes each. The unit, Recycling as a Pathway to Environmental Literacy, replaced the usual instruction in the experimental class, whereas the comparison class continued teacher-led instruction

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without collaborative project or engineering-design activities. The teacher divided the experimental class into five groups. Students collaborated within their groups to propose ideas, plan their projects, construct and refine artifacts, and present their work. The teacher introduced the design challenges, provided safety and materials guidance, supported planning and measurement, monitored group progress, and facilitated feedback, refinement, and final sharing. The three phases focused respectively on problem framing and planning, artifact construction under design constraints, and refinement, reflection, and communication. Materials included old shirts, needles and thread, plastic bottles, bottle caps, a wooden notice board, wooden sticks and pinecones for the bird-feeding station, and paper cups and plastic straws for the anemometer. Reflection was incorporated through teacher feedback, group refinement, and the final gallery walk. No formal fidelity-monitoring instrument, structured observation protocol, teacher log, artifact-rating rubric, or group-process measure was used. Implementation documentation was limited to the planned instructional sequence and process photographs or videos, while the teacher and researcher supervised the activities. Accordingly, the study illustrates one intended classroom enactment of STEM-PBL but does not quantify implementation fidelity or quality. The same questionnaire was administered immediately before and after the unit and required approximately 10–15 minutes to complete. The overall data-collection period was approximately one month. Table 1 summarizes the implemented sequence, activities, STEM elements, and intended environmental literacy focus.

From an implementation perspective, the unit was deliberately built around resources that were already obtainable in or around the school rather than around specialized equipment. The five groups worked with discarded clothing, plastic bottles, bottle caps, wood, pinecones, paper cups, plastic straws, needles, and thread. The common structure did not require every artifact to contain the same balance of science, technology, engineering, and mathematics. Instead, integration was organized through a shared design logic: students identified a practical recycling or upcycling task, selected an idea, planned a tangible product, used measurement where relevant, worked with materials and tools under teacher supervision, responded to design constraints, refined the artifact after feedback, and explained how the finished product related to the environmental theme. The sequence also kept the environmental problem visible during construction rather than treating sustainability as a separate discussion added after the making activity. The old-shirt bag and bottle planters connected reuse with material decisions and functional design; the bird-feeding station connected construction with living systems; the anemometer introduced measurement through a simple device; and the bottle-cap logo linked reuse with public environmental communication. This organization documents a form of integrated STEM-PBL that can be examined and replicated as an instructional sequence. The teacher's role was equally concrete. She introduced the design challenges, supported planning and safety, monitored construction, facilitated feedback, and organized the final sharing. The researcher provided structured guidance before and during implementation, but no independent fidelity instrument was used. The resulting account therefore documents what was planned and carried out under these classroom conditions while leaving questions of implementation quality, consistency across teachers, and transferability to other schools for subsequent studies.

Despite differences in artifact type and STEM emphasis, all groups followed a shared instructional sequence comprising problem framing, collaborative planning, material selection, construction under teacher guidance, refinement following feedback, and communication of the environmental rationale. This variation is important to a STEM-focused interpretation because it illustrates how a single, approximately four-week STEM-PBL unit can integrate STEM practices through diverse design challenges. Each challenge offered distinct entry points into materials, measurement, tool use, engineering constraints, and communication while maintaining a shared sustainability theme. The old shirt-to-bag and bottle planters were primarily upcycling tasks that foregrounded material reuse and design constraints, with a stronger focus on responsible consumption and waste reduction. The bird-feeding station emphasized links between human actions and living organisms, while connecting design choices to everyday practices that can support local biodiversity. The anemometer project placed greater emphasis on measurement and simple data-related reasoning through constructing and using a device, alongside engineering design considerations. Finally, the bottle-cap logo functioned as an awareness-oriented artifact highlighting communication and community messaging as part of environmental responsibility. Because one class represented each condition and no project-specific engagement or outcome measures were collected, the study could not determine whether particular projects were more engaging or effective than others. Because no project-specific process or outcome measures were collected, the five projects are treated as components of a single instructional unit rather than as separate interventions.

Example project (old shirt to bag): The old-shirt-to-bag project illustrates one example of the unit's intended STEM integration. Students used sketches and basic measurements to plan a functional product, considered textile materials and textile waste, used simple tools safely, and refined the product under teacher guidance. The activity combined mathematical measurement, discussion of material properties, purposeful tool use, and design under functional constraints. Table 1 provides further details.

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Table 1

Unit structure, implemented STEM elements, and intended environmental literacy focus

Component	What students did (as implemented)	STEM elements	Intended environmental literacy focus
Unit starts (phase 1)	Following the teacher's introduction, the teacher divided the class into five groups; each group proposed three feasible recycling or upcycling ideas; the ideas were discussed as a class; one idea was selected for each group; and initial planning began through sketches and basic measurements where applicable.	Collaborative problem framing; planning for a tangible product; basic measurement where applicable	Recycling and upcycling were introduced as practical responses to environmental issues.
Project work (phase 2)	Groups constructed artifacts with teacher guidance; brief safety/materials reminders; process documentation (photos/videos where applicable)	Hands-on making under teacher scaffolding; tools and simple construction techniques; design constraints ensuring functionality	Intended to connect STEM design activity with environmental challenges.
Refinement and sharing (phase 3)	Groups completed/refined artifacts with teacher feedback; short gallery walk with presentations linking design choices to recycling/upcycling goals	Iteration/refinement; communicating design choices in a sustainability context	Intended to reinforce the rationale for recycling and upcycling through reflection and communication.
Project artifacts (one per group)	Bags from old shirts; bird-feeding station; anemometer; planters made from plastic bottles; environmental awareness logo made of bottle caps on a wooden notice board	Artifact-based design and construction involving different combinations of STEM practices.	Shared emphasis on recycling, upcycling, reuse, and environmental responsibility.
Exemplar project: old shirt to bag	Students brought old shirts (with parental approval); planned using sketches and basic measurements; cut and hand-sewed fabric (needle and thread; no sewing machine); short discussions on textile materials and environmental implications of textile waste; safe tool use; photos/videos; supervised construction/refinement	Math: basic measurements; Science: textile materials/basic properties; Technology: tools + simple construction (needle and thread); Engineering: design constraints for a functional artifact	Intended to support awareness of waste reduction and reuse, encourage responsible consumption and waste-management tendencies, and emphasize personal responsibility.

Data analysis

Descriptive statistics, including means and standard deviations, were calculated for the three questionnaire-based, self-reported environmental literacy components: positive environmental behavioral tendencies, environmental awareness and perceived knowledge, and negative environmental behavioral tendencies. All 62 students provided usable questionnaires at both measurement occasions, with complete data for all three subscales; therefore, no imputation, listwise deletion, or pairwise deletion was required. The same students completed the questionnaire before and after the unit, but the anonymous questionnaires could not be matched at the individual level.

Because the two occasions represented repeated observations from the same students, they were not treated as independent samples. At the same time, the absence of individual linkage prevented estimation of the within-student covariance required for conventional paired or repeated-measures analyses. Accordingly, no inferential test of pre-to-post change was conducted. Group × Time ANOVAs, independent-samples tests comparing the two occasions within a class, individual change scores, baseline-adjusted ANCOVA, and standardized pre-to-post effect sizes were not used. Instead, the analysis reports class-specific pre-test and post-test means and standard deviations together with raw mean differences (post-test M minus pre-test M). These quantities describe aggregate

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score patterns across occasions and are not interpreted as estimates of individual change or causal intervention effects.

Given the bounded three-point response format and the marked concentration of post-test scores near the scale limits, raw mean differences were emphasized rather than standardized effect sizes. Standardized pre-to-post differences would be especially unstable when observed post-test variability is strongly compressed. The descriptive summaries are therefore interpreted in relation to the scale range, observed means, and standard deviations.

Consistent with the two research questions and the unlinked repeated observations, the analysis comprised descriptive procedures only. Post-test correlations among the three subscales were not used as a separate analytical component because the experimental-class post-test distributions were strongly compressed near the limits of the three-point scale, making associations difficult to interpret under severe range restriction. No gender-specific pre-to-post analysis was used, because the measurement occasions were individually unlinked and the single experimental class provided only small descriptive subgroups. The reported analyses therefore remain centered on baseline values and class-specific pre-test and post-test means, standard deviations, and raw mean differences.

STEM achievement outcomes were not assessed directly. STEM was treated as an instructional process embedded within the intervention rather than as a measured learning outcome.

RESEARCH FINDINGS

Baseline (pre-test) levels of the measured environmental literacy components

Table 2 summarizes the baseline descriptive statistics for the three questionnaire-based, self-reported environmental literacy components: positive environmental behavioral tendencies, environmental awareness and perceived knowledge, and negative environmental behavioral tendencies.

Table 2

Pre-test means and standard deviations for the three self-reported environmental literacy components (N = 62)

Environmental literacy component	M	SD
Positive behavioral tendencies	2.53	0.17
Environmental awareness and perceived knowledge	2.16	0.27
Negative behavioral tendencies	1.61	0.33

Note. All three components were measured using student self-reports.

As shown **in Table 2**, the mean pre-test score was 2.53 (SD = 0.17) for self-reported positive environmental behavioral tendencies, 2.16 (SD = 0.27) for environmental awareness and perceived knowledge, and 1.61 (SD = 0.33) for self-reported negative environmental behavioral tendencies. Because no predefined interpretive cutoffs were established for the subscale scores, these values are reported descriptively.

Class-Level Score Patterns Across Measurement Occasions

As shown in **Table 3**, the experimental and comparison classes showed numerically close pre-test means across the three measured outcomes. The experimental class showed larger favorable raw mean differences across occasions than the comparison class for positive behavioral tendencies (+0.42 vs. +0.11), environmental awareness and perceived knowledge (+0.77 vs. +0.20), and negative behavioral tendencies (−0.54 vs. −0.09), for which lower scores represented more favorable self-reports. The descriptive difference between the two class-level raw mean differences was +0.31 for positive behavioral tendencies, +0.57 for environmental awareness and perceived knowledge, and −0.45 for negative behavioral tendencies.

These values are descriptive summaries of two class-level score distributions at each occasion. They are not estimates of within-student change, and no p values or repeated-measures effect-size estimates are reported because the anonymous pre- and post-test responses could not be linked. The experimental-class post-test means were close to the limits of the three-point scale (2.95, 2.96, and 1.02), and the corresponding post-test standard deviations were 0.07 for all three outcomes. This strong compression of observed variability further supports emphasizing raw score differences rather than standardized pre-to-post effect sizes.

Table 3

Descriptive pre-test and post-test class-level scores and raw mean differences

Component	Class	Pre M	Pre SD	Post M	Post SD	Raw ΔM
Positive behavioral tendencies	Experimental (n = 32)	2.53	0.17	2.95	0.07	+0.42
Positive behavioral tendencies	Comparison (n = 30)	2.52	0.17	2.63	0.22	+0.11

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Environmental awareness and perceived knowledge	Experimental (n = 32)	2.19	0.26	2.96	0.07	+0.77
Environmental awareness and perceived knowledge	Comparison (n = 30)	2.13	0.29	2.33	0.44	+0.20
Negative behavioral tendencies	Experimental (n = 32)	1.56	0.36	1.02	0.07	−0.54
Negative behavioral tendencies	Comparison (n = 30)	1.66	0.30	1.57	0.38	−0.09

Note. Raw ⊿M = post-test M − pre-test M. For negative environmental behavioral tendencies, a negative raw difference indicates lower endorsement of environmentally undesirable tendencies. The raw differences are descriptive and are not individual change estimates or causal effect estimates.

DISCUSSION

The principal class-level pattern was that the experimental class showed larger favorable differences between pre-test and post-test means than the comparison class across all three self-reported outcomes: positive environmental behavioral tendencies, environmental awareness and perceived knowledge, and negative environmental behavioral tendencies. However, the anonymous questionnaires could not be linked at the individual level, and each condition was represented by only one intact class. The observed differences therefore represent class-level score patterns rather than individual change estimates or causal intervention effects.

Favorable differences between pre-test and post-test means were also observed in the comparison class, although they were smaller. These are aggregate, occasion-specific contrasts within two different intact classes. The larger numerical differences in the experimental class cannot be attributed to the STEM-PBL unit because instructional condition and class coincide completely. Pre-existing class characteristics, regular classroom processes, exposure to the environmental topic, repeated questionnaire administration, novelty, collaborative activity, differential attention, teacher or researcher expectations, and other unmeasured influences cannot be separated from the condition contrast. The appropriate interpretation is therefore purely comparative and descriptive: the two classes displayed different pre-test-to-post-test mean patterns across the three self-reported outcomes. This pattern characterizes the two classroom distributions observed in the study; it is not evidence that the unit produced the differences.

The instructional enactment can nevertheless be situated alongside prior work on integrated STEM-PBL in primary settings (Wan et al., 2023; Winarni et al., 2022) and sustainability education that incorporates hands-on, locally relevant learning activities (Calliera et al., 2026).This comparison situates the classroom design within prior STEM-PBL and sustainability education research without implying confirmation of previously reported outcomes. The design aligns with pedagogical approaches that organize learning around authentic problems, collaborative production, and the application of STEM practices. In the present unit, those principles were translated into a short sequence that could be accommodated within the regular science timetable and carried out with accessible materials rather than specialized laboratory or digital-programming equipment.

The Arabic-speaking school context is relevant because environmental learning in Arab localities in Israel may be shaped by uneven infrastructure and reliance on local leadership or external partnerships (Negev & Garb, 2014). Students have also documented garbage disposal and limited recycling infrastructure as visible local concerns (Hayik, 2021). Related Israeli research with pre-service teachers has reported that structured sustainability initiatives may support willingness to act and related dispositions (Khazen et al., 2025).

The experimental condition differed from the comparison instruction in a bundle of interrelated features, including collaborative planning, hands-on artifact construction, use of materials and tools, iterative refinement, and public presentation. Because these features were implemented together and were neither manipulated nor measured separately, the study cannot determine whether the observed score patterns were associated with the integrated unit as a whole or with any particular component.

The theoretical perspectives used in the study are most informative as a way to describe the instructional logic of the unit, not as explanations for the observed score differences. Action competence emphasizes opportunities for learners to plan and enact informed action (Jensen & Schnack, 2006), while knowing-doing gap accounts show why environmental knowledge or concern alone does not guarantee sustained behavior (Kollmuss & Agyeman, 2002). The Theory of Planned Behavior likewise distinguishes attitudes, perceived control, intentions, and behavior (Ajzen, 1991). In the implemented unit, students encountered environmental ideas through concrete design tasks that required planning, making, revision, and communication. These features created classroom opportunities to connect sustainability content with visible products and practical decisions. The study did not measure action competence, perceived agency, behavioral intentions, durable behavior, transfer beyond the classroom, or the mechanisms through which particular activities may have influenced students. Accordingly, these theories frame

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the pedagogical rationale for the enactment and identify constructs for future research; they do not provide a basis for inferring why the two classes displayed different score patterns.

Assessment of environmental literacy in primary school students

The baseline findings showed mean scores of 2.53 for self-reported positive environmental behavioral tendencies, 2.16 for environmental awareness and perceived knowledge, and 1.61 for self-reported negative environmental behavioral tendencies. Because no predefined interpretive cutoffs were established, these scores should be understood descriptively rather than classified as low, moderate, or high. The findings can nevertheless be considered alongside literature showing that children may express environmental awareness and concern while the translation of such orientations into sustained action remains complex (Goldman et al., 2018; Liefländer et al., 2013). Research has further suggested that environmental education in primary curricula may remain more theoretical than action-oriented (Ricoy & Sánchez-Martínez, 2022), while Israeli research has noted that recycling may receive greater attention than broader consumption practices (Goldman et al., 2018). Socio-scientific issue contexts that require decision-making and argument construction may provide another route for connecting environmental understanding with action-oriented reasoning (Sakamoto et al., 2026). However, because the present study did not include objective knowledge measures or observed behavior, its baseline findings do not directly demonstrate a knowing–doing gap.

Class-level score patterns across the two instructional conditions

The experimental class showed larger favorable raw mean differences between the pre-test and post-test class means than the comparison class across the three self-reported outcomes. The experimental-class post-test means of 2.95 and 2.96 on the positively scored outcomes and 1.02 on the negatively scored outcome were close to the limits of the three-point scale, with SD = 0.07 for each. This concentration indicates pronounced ceiling and floor patterns and makes standardized pre-to-post differences especially unstable. For that reason, the report emphasizes raw mean differences and does not estimate standardized pre-to-post effect sizes. The numerical contrasts are presented only as descriptions of the two classes at the two occasions. They do not establish gains in STEM achievement, individual behavioral change, improvement in environmental literacy, or causal intervention effectiveness. Their value is to document the score context surrounding one classroom enactment and to show why replication with individually linked observations and multiple independent classes within each condition is necessary before effectiveness can be evaluated.

The five design products provided different entry points into measurement, materials, construction, living systems, and environmental communication while maintaining a shared sustainability theme (Table 1). This is the main practical contribution of the study: it records how integrated STEM-PBL was enacted through several distinct but structurally related projects within the same short unit. Each group worked through a common sequence of selecting a problem, planning a product, choosing and using materials, constructing under constraints, refining with feedback, and communicating the environmental rationale. At the same time, the unit allowed variation in the STEM practices emphasized by each artifact. The anemometer foregrounded measurement and device construction; the old-shirt bag and bottle planters foregrounded reuse, material decisions, and functional design; the bird-feeding station connected design choices with living systems; and the bottle-cap logo emphasized environmental communication. Because project-specific process and fidelity data were not collected, these differences cannot be ranked or linked to the questionnaire patterns. They instead provide a concrete record of the instructional possibilities and boundaries of this particular enactment.

The study provides a classroom-level record of the implemented instructional design without estimating its instructional impact. Three features of that record are especially relevant to future replication. First, the intervention specifies a manageable temporal structure: twelve 45-minute lessons distributed across approximately four weeks, with the work moving from problem framing and planning to construction and then to refinement and communication. Second, it specifies the material and organizational demands of the enactment, including five small groups, readily available reusable materials, teacher supervision, simple tools, and project-specific design constraints. Third, it shows how a single sustainability theme can accommodate heterogeneous artifacts while retaining a common instructional architecture. This level of specification is useful because feasibility in ordinary schooling depends not only on the pedagogical idea but also on whether the sequence can be fitted into scheduled lessons, supported by the available teacher, and carried out with materials that do not require specialized facilities. In this study, the unit was implemented during the regular science timetable, and the comparison class continued its usual teacher-led work during the same period. These details make the unit inspectable as a design that other researchers can reproduce, adapt, or test under stronger designs. At the same time, the available evidence does not establish consistency of implementation across teachers or schools, nor does it attribute the observed questionnaire distributions to the unit. Completing the planned sequence in one experimental class does not demonstrate that

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another teacher would enact it with the same fidelity, that students in another school would respond similarly, or that the observed questionnaire distributions resulted from the unit. The descriptive score patterns therefore serve as contextual information about this enactment, while the principal contribution lies in specifying the classroom arrangement that generated the learning experience. A subsequent effectiveness study would need to preserve these documented features while adding independent fidelity measures, multiple classrooms per condition, individually linked repeated observations, and outcomes less vulnerable to ceiling, floor, and common-method constraints.

CONCLUSIONS AND IMPLICATIONS

In this two-class pilot study, the experimental class showed larger favorable raw mean differences between pre-test and post-test class means than the comparison class across three questionnaire-based, self-reported outcomes: positive environmental behavioral tendencies, environmental awareness and perceived knowledge, and negative environmental behavioral tendencies. Because individual pre- and post-test questionnaires could not be linked and each condition was represented by only one intact class, these descriptive patterns do not establish individual change or causal intervention effectiveness. They also should not be interpreted as evidence of improvement in environmental literacy as a whole, because the instrument assessed only the three specified self-reported components.

The study also illustrates one classroom enactment of integrated STEM-PBL in the early grades. The unit used bounded design challenges, simple measurements, tools, material-related decisions, iterative refinement, structured collaboration, and teacher scaffolding. Recycling and upcycling materials offered an accessible basis for design work without specialized or costly equipment, and the sequence was completed within 12 regular science lessons over approximately four weeks. In this study, feasibility refers solely to the completion of the planned activities within the regular classroom timetable using the available teacher support and materials. It does not mean that implementation quality was independently verified, that the same design will be equally workable in other schools, or that the unit has been shown to improve student outcomes. The educational contribution therefore lies in documenting a replicable instructional example whose effectiveness remains an open empirical question. Future evaluations require multiple classes and schools, individually linked observations, stronger outcome measures, and systematic implementation-fidelity evidence before claims about effectiveness or scalability can be made.

Limitations and recommendations for future research

Several limitations should be considered. First, the study included only two intact classes from one school, with one class randomly assigned at the class level to each condition. Although the class-level allocation was random, only one class represented each condition; consequently, condition remained inseparable from class, and no independent class-level replication was available. The student-level findings should therefore be interpreted cautiously, because the observed differences may partly reflect characteristics specific to the two participating classes.

In addition, although the same students participated at both measurement occasions, the anonymous questionnaires could not be linked at the individual level. The study therefore could not estimate within-student change, examine whether students with different baseline scores showed different patterns across occasions, adjust post-test outcomes for individual baseline values, or estimate the within-student covariance needed for conventional repeated-measures inference. For this reason, inferential tests of pre-to-post change were not used. Consequently, the observed differences between pre-test and post-test scores represent occasion-specific class-level score patterns rather than longitudinal change within individual students.

The comparison class received regular teacher-led instruction and was not matched to the experimental class for collaborative planning, hands-on artifact construction, iterative refinement, or public presentation. Because each instructional condition was represented by a single intact class, condition and class were fully confounded. The observed score patterns therefore cannot be attributed to STEM integration, the instructional package as a whole, or any particular component. The design cannot distinguish instructional influences from pre-existing class characteristics or other unmeasured factors. Novelty, social interaction, differential attention, teacher or researcher expectations, and demand characteristics were not assessed separately, and their contributions, if any, cannot be determined. Accordingly, the comparisons are interpreted solely as descriptive class-level score patterns.

Second, the outcomes were measured immediately after the unit using a three-point self-report questionnaire completed by fourth-grade students. Several items addressed recycling, waste reduction, and environmental responsibility and therefore closely reflected the unit content. Responses may have been influenced by the recent salience of these topics, item-content overlap, social desirability, or demand characteristics. The high and low post-test means indicate pronounced ceiling and floor effects that compressed score variability, while the three-point response format may have further limited sensitivity to differences among students. Under this degree of range restriction, post-test correlations among subscales from the same questionnaire would have limited interpretability

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and were not used as a separate analytical component. Item-level response distributions were not examined. Because standardized differences can become unstable when variance collapses near scale limits, standardized pre-to-post effect sizes were not reported.

Third, the study relied on self-reported behavioral tendencies and perceived awareness and knowledge. It did not include direct behavioral observations, objective knowledge measures, or qualitative evidence of students' learning processes. This limits the ability to validate the questionnaire-based score patterns and identify the mechanisms that may have contributed to them.

Fourth, project-level process data, including iteration frequency, design rationales, measurement use, group participation, and artifact quality, were not collected. The study therefore could not connect particular project types or design features with the magnitude of the observed class-level score differences. Direct measures of STEM learning and systematic indicators of implementation fidelity were also not included. Consequently, conclusions concerning STEM are limited to the instructional process and cannot be extended to gains in STEM knowledge, skills, or performance.

Future research should replicate the unit across multiple schools and include multiple classes within each condition, preferably using cluster-randomized designs with a sufficient number of classes to support multilevel analyses that account for the nesting of students within classrooms. Future pretest-posttest studies should use confidential participant-generated linkage codes or another ethics-approved procedure to match repeated responses without collecting direct personal identifiers. This would permit the estimation of within-student change, adjustment for baseline scores, and examination of whether score patterns differ according to students' initial levels. Delayed follow-up assessments are also needed to examine whether the observed score patterns persist beyond the immediate post-test.

Future studies should triangulate questionnaire findings with classroom observations, direct behavioral indicators, student and teacher interviews, artifact-quality assessments, objective knowledge tests, and systematic measures of implementation fidelity. Project-level process measures should document iteration frequency, measurement practices, design rationales, group participation, and collaborative discourse. Larger multi-site studies can then examine contextual and subgroup variation within designs that include sufficient numbers of classrooms for valid comparative inference, while also assessing differences in students' opportunities to learn.

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Ethical Statement

The study was approved for implementation in schools by the Office of the Chief Scientist of the Israeli Ministry of Education. Under the regulations of the Arab Academic College for Education in Israel–Haifa, the study qualified for exemption from additional institutional ethics committee review because it involved minimal-risk educational procedures and anonymous questionnaire data. Parents or legal guardians provided written informed consent, and participating students provided assent. Separate written parental permission was obtained for the collection and publication of photographs and videos. All faces and other identifying features were masked, and no identifiable media were included in the manuscript or supplementary materials. Participation was voluntary, and the questionnaire data were used solely for research purposes.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions

N.K.: led the study and took primary responsibility for Conceptualization, Data Collection, Data Analysis and Interpretation, and Writing – Original Draft. N.B.: contributed to Conceptualization, Data Analysis and Interpretation, and Writing – Review & Editing. K.D.F.: contributed to Writing – Review & Editing. All authors reviewed and approved the final manuscript.

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Data availability

The anonymous pre- and post-test questionnaires were not linked at the individual level, and no individually matched longitudinal dataset is available. The aggregate statistics reported in the manuscript constitute the data available for the analyses presented.

AI disclosure

Generative AI tools were used solely for language editing and clarity. The authors independently verified all scientific content, numerical results, statistical analyses, interpretations, citations, and references and assume full responsibility for the manuscript.

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