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Research paper

A Preliminary Classroom Evaluation of a Gamified Augmented Reality Application for Conservation Learning in Primary STEM Education

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ABSTRACT

This study reports a preliminary classroom evaluation of a technology-supported instructional intervention for conservation learning in primary STEM education, using the culturally significant Bua Kheo Mongkol (Nymphaea khaomongkol; Thai: Bua Kheo Mongkol) as the local context. The pedagogical design and activity set were developed and refined through a multi-round Delphi process involving nine experts in educational technology, science/environmental education, and measurement/evaluation. The intervention was examined using a one-group pretest-posttest design with a two-week retention test involving 30 Grade 5 students. Knowledge outcomes were measured using the same 40-item multiple-choice test at pre-test (T1), post-test (T2), and retention (T3). Results showed a small but statistically significant increase in knowledge scores from T1 to T2, while T3 scores remained similar to T2, suggesting short-term maintenance of the modest gain. Post-intervention student feedback on usability, engagement, learning support, local relevance, intention to apply learning, and overall satisfaction was generally positive at the item level. Overall, the findings suggest that a culturally grounded, technology-supported classroom intervention was associated with modest knowledge improvement and positive descriptive student feedback. However, the one-group design and measurement limitations mean that stronger causal claims should be avoided, and future comparative studies are needed to test effectiveness more rigorously.

Keywords: gamified augmented reality, primary STEM education, conservation knowledge, place-based learning, cultural relevance

Conservation education is an important component of environmental learning in primary school, yet traditional classroom approaches may not always sustain student attention or make complex ecological content easy to understand for young learners (Corres et al., 2020). Approaches that rely mainly on factual transmission may be less effective for supporting comprehension and classroom engagement with environmental topics (Batri et al., 2022). For this reason, there is growing interest in interactive and immersive learning approaches that can make conservation content more accessible and meaningful in school settings. In this context, educational technologies such as augmented reality (AR), virtual reality (VR), and gamification offer promising ways to present ecological concepts in more concrete, visual, and motivating forms, helping connect classroom instruction with observable environmental content (Lim et al., 2024; Shihab et al., 2023).

Using locally meaningful biodiversity content may further strengthen the relevance of conservation learning for primary students (Akleman et al., 2019). In Thailand, the Bua Kheo Mongkol provides a culturally and ecologically relevant context for such learning. It is associated with local heritage and is also recognized within

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broader plant conservation efforts, including Thailand's Plant Genetic Conservation Project initiated by Her Royal Highness Princess Maha Chakri Sirindhorn. Reports of lotus decline in some areas also highlight the value of strengthening students' understanding of its ecological significance and conservation-related content, especially among younger learners who may have limited prior knowledge of its role in local ecosystems (Sugiarto et al., 2023).

To address this educational context, the present study developed and examined a technology-supported classroom learning intervention for Grade 5 students focused on Bua Kheo Mongkol conservation. The intervention combined gamification, AR-supported content, and interactive storytelling within a structured instructional sequence. The study focused on two outcomes: (1) students' conservation knowledge and (2) students' post-intervention feedback on the learning experience. Accordingly, this study addresses two research questions: (1) To what extent was the intervention associated with changes in students' conservation knowledge? and (2) How did students rate their experience with this technology-supported learning sequence? By grounding digital learning in a locally meaningful conservation context, this study aims to contribute preliminary classroom evidence on the use of interactive technology to support conservation learning in primary STEM education.

LITERATURE REVIEW

To inform the design of the intervention, this study drew on four pedagogical approaches discussed in prior literature and synthesized them into a conceptual model. While these pedagogical approaches have shown promise in prior work, their use in school settings also presents important challenges. For example, AR and other immersive media may increase cognitive load if visual information, instructions, and interactive elements are not carefully scaffolded for young learners. Gamification can improve attention and participation, but some studies note that it may also encourage short-term or surface-level engagement if reward structures dominate conceptual understanding (Akhiyar et al., 2026). In addition, when multiple instructional components—such as AR, gamified tasks, teacher explanation, reflection, and observation—are combined in a single intervention, it becomes difficult to isolate the specific contribution of each element (Ben-Othman & Hariguna, 2026; Salem & Aqel, 2026). For this reason, the present review treats these approaches as potentially useful but not uniformly effective and positions the current study as a preliminary classroom evaluation of a multi-component learning sequence rather than a test of any single mechanism.

Gamified educational modules

To address the low engagement often reported in traditional environmental education, the application incorporated gamification as a potential support for student motivation and participation. This approach includes game-like elements such as points, badges, and narrative-driven missions, which have been associated with increased engagement and participation in sustainability-related learning activities (Lim et al., 2024; Rao et al., 2022). By providing immediate feedback and rewards for tasks such as virtual tree planting or recycling challenges, gamification may help make learning activities more structured and engaging for young learners (Oladele et al., 2024). At the same time, the educational value of gamification depends on how well the reward structure is aligned with the learning objectives. Points, badges, and competition can encourage participation, but they may also promote short-term or surface-level engagement if students focus more on rewards than on conceptual understanding (Widodo & Afuan, 2026; Putri & Mukti, 2025). For this reason, the present study treats gamification as a supportive design element within a broader instructional sequence, rather than as an independently tested causal mechanism.

Augmented reality (AR) experiences

AR was incorporated to help present abstract conservation concepts in a more concrete and visually accessible form. Prior research suggests that AR can support interactive learning by allowing students to visualize and explore digital representations of ecological content within their physical environment (Mercier et al., 2023). In primary education contexts, such features may help students better notice, describe, and discuss biodiversity-related concepts that might otherwise remain difficult to imagine through text-based instruction alone (Öztürk, 2023; Shihab et al., 2023). From a pedagogical perspective, AR can support active inquiry by enabling learners to interact with visual models in context rather than only receiving information passively. However, AR-based learning may also introduce additional cognitive demands, especially for younger learners, if visual overlays, instructions, and interaction tasks are not carefully scaffolded (Widodo & Santoso, 2025; Endahti & Jalaludin, 2025). Accordingly, AR is treated in this study as a potentially useful feature for supporting understanding and engagement, while recognizing that its specific contribution cannot be isolated from the other instructional components used in the intervention.

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Narrative-driven education

A narrative-driven framework was included to make conservation content more understandable and contextually meaningful for primary school students. Storytelling can help organize information into a more memorable sequence and may support young learners in relating abstract environmental issues to familiar situations and values (Yang et al., 2022). By embedding learning content within storylines that include cultural context, challenges, and guided activities, narrative structures may help make conservation topics easier to follow and discuss in classroom settings (McCormack et al., 2021). At the same time, narrative appeal does not automatically ensure deeper conceptual learning. Stories may increase attention and emotional interest, but their educational value depends on how clearly, they are connected to the intended learning goals (Warmayana et al., 2025; Pratama & Wahid, 2025). In the present study, narrative design is therefore treated as a contextual support for meaning-making and recall, rather than as a separately tested source of learning gain. The use of local cultural references, such as stories related to Bua Kheo Mongkol, was intended to strengthen relevance, while the current study evaluates only immediate classroom outcomes rather than longer-term attitudinal or behavioral change.

Practical conservation initiatives

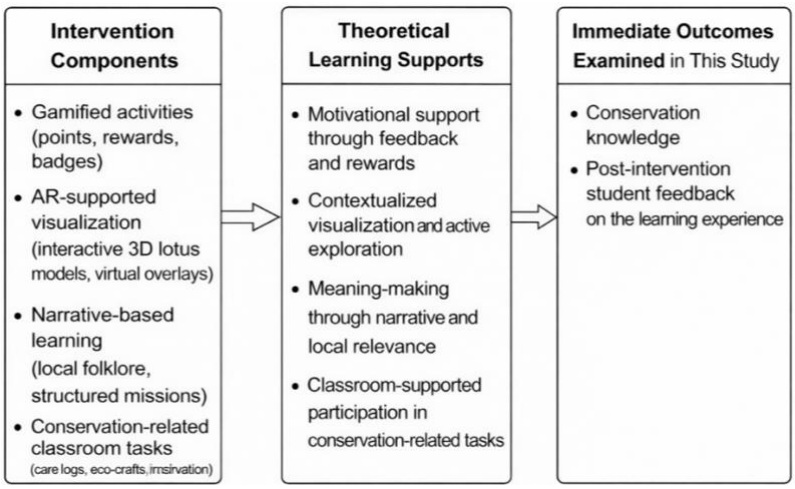
To increase the local relevance of classroom learning, the intervention design drew on practical conservation-oriented activities. Previous work suggests that hands-on experiences, such as observing local biodiversity or participating in simple conservation-related tasks, can help students connect environmental concepts with observable situations in their surrounding context (Hale et al., 2021; Jordan et al., 2016). In this sense, practical activities may support classroom understanding by making conservation content less abstract and more locally meaningful. However, the presence of practical or community-linked elements does not by itself demonstrate long-term environmental responsibility or sustained conservation behavior. Such outcomes require direct behavioral measures and longer follow-up than were included in the present study. Accordingly, practical conservation initiatives are discussed here as context-enriching components of the broader instructional design, rather than as outcomes verified by the current data. Their role in this study is mainly to support the relevance and coherence of the learning sequence surrounding the app-based activities. Given the classroom-based and preliminary nature of the present study, the most immediate outcomes of interest were students' conservation knowledge and their post-intervention perceptions of the learning experience, rather than longer-term stewardship or verified conservation behavior.

Conceptual model of the intervention

To synthesize the pedagogical considerations described above, Figure 1 presents the conceptual rationale used to inform the design of the intervention. The figure links selected app features with learning mechanisms suggested in prior literature, such as active inquiry, contextualized visualization, and motivational support. In this sense, the model serves as a design framework for organizing the intervention components rather than as a validated causal model. In the present study, it was used to guide the structure of the technology-supported learning sequence and to justify the immediate outcomes examined, namely conservation knowledge and students' post-intervention perceptions of the learning experience.

Figure 1

Conceptual framework informing the intervention design



METHOD

Research designs and participants

This study employed a one-group pretest-posttest design with a retention test to conduct a preliminary classroom evaluation of changes in students' conservation knowledge and post-intervention feedback following the technology-supported learning sequence. The procedure comprised a pretest (T1), the intervention using the technology-supported learning sequence (X), a posttest (T2), and a retention test administered two weeks later (T3) to examine short-term retention of conservation knowledge about the Bua Kheo Mongkol. Because no comparison group was included, the design was intended to provide preliminary classroom-based evidence only and does not permit strong causal attribution of observed changes to the intervention alone.

The broader population consisted of 850 fifth-grade students from 74 institutions within the Rajamangala University of Technology Thanyaburi (RMUTT) school network, all of which have access to educational resources and conservation initiatives associated with the Plant Genetic Conservation Project. From this population, a purposive sampling strategy was used to recruit 30 Grade 5 students (aged 10–11 years) from three RMUTT network schools (10 students per school). Inclusion criteria were: (a) enrolment in Grade 5 at a network school, (b) regular attendance and ability to participate in all study sessions, and (c) willingness of the school and parents to engage in a conservation-focused educational activity. All three schools had previously participated in Bua Kheo Mongkol conservation activities under the Plant Genetic Conservation Project, ensuring that the application content was contextually meaningful for the participants. Basic demographic and technology-related characteristics are summarised in **Table 1**; the sample comprised 13 boys and 17 girls, and most students reported access to a smartphone or tablet at home.

Table 1

Participant characteristics

Variable	Category	n	%
Gender	Boys	13	43.3
	Girls	17	56.7
Age	10 years	16	53.3
	11 years	14	46.7
School	School 1 (RMUTT network)	10	33.3
	School 2 (RMUTT network)	10	33.3
	School 3 (RMUTT network)	10	33.3
Device access at home	Owns smartphone/tablet	20	66.7
	Shares device with family	8	26.7
	No regular device access	2	6.7

This study was conducted in accordance with applicable ethical standards for research involving minors. Ethical approval for the study protocol was obtained from Rajamangala University of Technology Thanyaburi. Prior to participation, written informed consent was obtained from parents or legal guardians, and assent was obtained from the participating students. Participation was voluntary, and students could withdraw at any time without penalty. To protect confidentiality, no personally identifying information is reported. Each student was assigned a unique study ID, and all analyses were conducted using anonymized data. Data were stored and accessible only to the research team.

The educational intervention

The intervention was a technology-supported classroom learning sequence centered on a mobile AR application together with teacher-guided classroom activities focused on the conservation of the Bua Kheo Mongkol, a culturally and ecologically significant species in Thailand. The application content addressed three core topics: (1) cultivation methods for the Bua Kheo Mongkol, (2) its cultural significance in Thai society, and (3) sustainable products and uses derived from the plant. The app presented AR visualisations of the Bua Kheo Mongkol together with game-based missions and immediate feedback. When students scanned a printed marker or image of the lotus, the application overlaid digital content onto the real-world view, highlighting key plant structures (e.g., petals, sepals, stamens) and their functions. As illustrated in **Figure 2**, the Bua Kheo Mongkol appeared in the camera view with labels identifying its parts, a short explanatory caption, and in-app reward icons (trophy, star, and green check mark) that signaled successful task completion. In this way, gamification elements

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(points, rewards, and confirmation) were embedded directly within the AR interface rather than presented as a separate game layer.

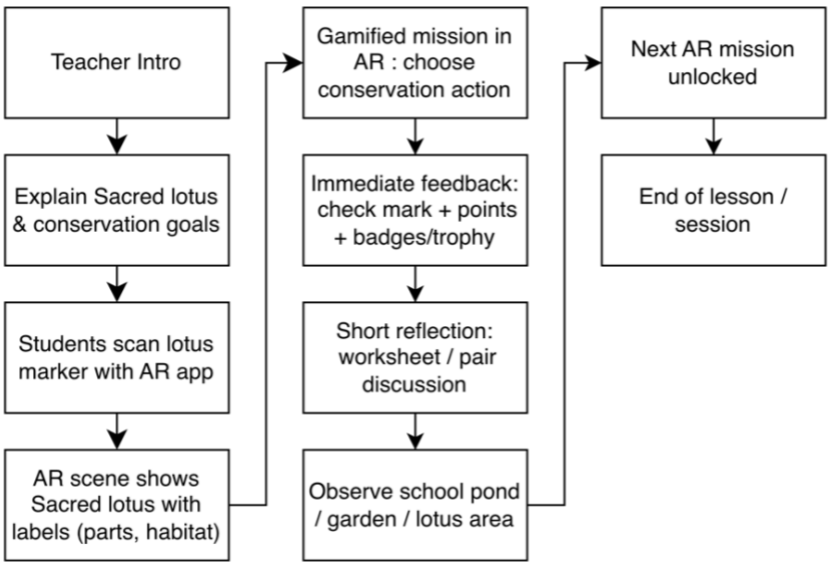
Figure 2

Example of the gamified AR interface used in the intervention

Each lesson followed a repeated instructional flow that integrated AR scenes with classroom activities and game mechanics, as summarised in **Figure 3**. Sessions began with a brief teacher introduction in which the Bua Kheo Mongkol topic and lesson goals were explained, after which students used the app to scan the lotus marker and access the AR scene. Within this scene, they completed a gamified mission (e.g., choosing an appropriate conservation action or identifying the correct plant part), and their responses triggered immediate feedback in the form of check marks, points, and badges or trophy icons. Students then engaged in a short reflection activity, such as completing a worksheet or discussing their decisions with a partner, and when feasible they extended this learning by observing a school pond, garden, or lotus area to connect the AR experience with the local environment. Completion of one sequence unlocked the next AR mission, and the same instructional cycle was repeated as planned within each session. Accordingly, the present study evaluates the combined technology-supported instructional sequence—including teacher guidance, app-based interaction, worksheet/reflection activities, and local observation where feasible—rather than the isolated effect of the mobile application as a standalone tool.

Figure 3

Learning flow with mobile AR app



The intervention was implemented across three classroom sessions, each lasting approximately 50 minutes. Across sessions, the teacher's role was to introduce the lesson objective, explain how to access and use the AR

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activity, facilitate transitions between app-based and classroom-based tasks, and guide short reflection or discussion activities. The teacher did not provide direct answers to the knowledge-test items but supported students in using the technology and completing the assigned learning tasks. To promote consistency across participating schools, the same lesson structure, learning objectives, app activities, and worksheet/reflection sequence were used in each implementation. A simple implementation checklist was followed to ensure that the core components of the sequence—teacher introduction, AR interaction, gamified task completion, reflection/discussion, and local observation where feasible—were delivered in the intended order.

The pedagogical design of the intervention was informed and refined using a multi-round Delphi technique with a panel of nine specialists, each with a minimum of 5 years of professional experience in their respective fields: three experts in educational technology, three in science and environmental education (with familiarity in plant genetics and conservation), and three in assessment and evaluation. The Delphi process was used to support expert-based refinement of the intervention content, learning activities, and assessment indicators, rather than to establish empirical validity of the intervention in a stronger causal sense. The process followed four rounds. In Round 1, semi-structured interviews elicited expert views on key themes, learning outcomes, and activity types, which were coded and synthesised into an initial set of modules, activities, and assessment indicators. In Round 2, these proposals were converted into a structured questionnaire in which experts rated the relevance and feasibility of each activity on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree) and provided open-ended comments. In Round 3, experts received a summary of Round-2 results (item means and interquartile ranges) and anonymised qualitative feedback, then re-rated each item considering the aggregated group response. A final Round 4 focused only on items that had not yet reached sufficient agreement after Round 3, following minor wording revisions. Consensus was defined a priori as an item mean $\geqslant$ 4.0 and an interquartile range (IQR) $\leqslant$ 1.0; items meeting these thresholds were retained in the final intervention design, while items that remained below this criterion were revised for future development or excluded. For each round, descriptive statistics (mean, standard deviation, coefficient of variation, and IQR) were calculated to monitor changes in expert agreement and document convergence of opinions.

Instrumentation and Data Analysis

Data were collected from students using two instruments: (1) a knowledge test administered at three time points—pre-test (T1), post-test immediately after the intervention (T2), and a retention test two weeks later (T3)—and (2) a post-intervention student feedback questionnaire.

The knowledge instrument was a 40-item multiple-choice test designed to reflect the intervention's learning targets across seven domains. Domain 1 (8 items; Q1–Q8) covered plant type, cultivation conditions, propagation, care, and conservation-supporting practices. Domain 2 (3 items; Q9–Q11) focused on student participation in school-based conservation. Domain 3 (5 items; Q12–Q16) addressed benefits, threats, wise use, and conservation goals. Domain 4 (10 items; Q17–Q26) covered conservation concepts, cultural value, sustainability guidelines, and community participation. Domain 5 (7 items; Q27–Q33) addressed values, attitudes, and awareness-building activities. Domain 6 (4 items; Q34–Q37) focused on monitoring/documentation and app-supported learning activities. Domain 7 (3 items; Q38–Q40) addressed quiz-, AR-, and follow-up activity-related understanding. The items were developed to reflect the content and learning emphases of the intervention and were aligned with the Delphi-refined activity structure used to organize the instructional sequence. Each item was scored dichotomously (1 = correct, 0 = incorrect), and total performance at each time point was converted to percentage correct. The same test form was used at T1, T2, and T3 to support direct comparison of performance across time; however, repeated administration of the same form may also have introduced familiarity or practice effects and is therefore interpreted cautiously in the present study.

The post-intervention student feedback questionnaire consisted of 10 items rated on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). The items were intended to capture students' immediate perceptions of the learning experience across usability, engagement, perceived learning support, local relevance, perceived transfer, and overall satisfaction. Because the questionnaire was used to obtain descriptive feedback on specific aspects of the intervention rather than to establish a strong latent scale, responses were interpreted primarily at the item level. Internal consistency was examined for transparency; however, the resulting Cronbach's alpha was low in this sample, so the questionnaire is not interpreted in the present study as a robust scale-based measure. Instead, it is used as descriptive post-intervention student feedback to supplement the knowledge results.

Data analysis used descriptive statistics (n, mean, standard deviation, and selected distribution summaries such as minimum-maximum) to summarize both the knowledge results and the item-level student feedback responses. Changes in knowledge scores were examined using paired-samples t-tests (two-tailed, $\alpha = .05$) for the comparisons T1–T2, T2–T3, and T1–T3. Prior to conducting the paired comparisons, the normality of the difference scores was evaluated using the Shapiro-Wilk test. Because the data involved discrete, narrow scoring bands, non-parametric Wilcoxon signed-rank tests were also used as a robustness check when the normality

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assumption was violated. The student feedback questionnaire was analyzed descriptively at the item level and was not used as a strong unified scale for inferential interpretation.

RESULTS

Expert Evaluation and Consensus

The Delphi process provided expert-informed refinement of the application's design and activity set through iterative rating and re-rating. It was planned as four rounds, with Round 1 used for item generation and refinement and Rounds 2–3 used for quantitative rating and re-rating to confirm convergence; Round 4 was reserved as a contingency round if consensus was not achieved. Round 1 (item generation and refinement) employed semi-structured interviews (in person/telephone/email) to elicit expert views on key learning outcomes, content coverage, and appropriate activity types for strengthening conservation awareness of Bua Kheo Mongkol. Interview findings were coded and synthesised into a structured set of draft activity statements and indicators.

Round 2 (first quantitative rating) converted the Round-1 outputs into a structured questionnaire. Experts rated each proposed activity using a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). Item-level descriptive statistics (mean, standard deviation, coefficient of variation, median, and interquartile range) were computed across the nine expert ratings to characterise the initial level of agreement (**Table 2 would appear within Appendix**). At this stage, several items did not yet meet the a priori consensus threshold (mean $\geqslant$ 4.00 and IQR $\leqslant$ 1.00), indicating the need for clarification and refinement.

Round 3 (re-rating after feedback) provided experts with a Round-2 summary (central tendency and dispersion, including mean/median and IQR) together with anonymised qualitative comments. Experts then re-rated each activity item to assess whether opinions converged after reviewing the group response. The Round-3 results (**Table 3 would appear within Appendix**) show increased agreement across items relative to Round 2.

Consensus was defined a priori as mean $\geqslant$ 4.00 and IQR $\leqslant$ 1.00. Round 4 was reserved for items that failed to meet the consensus criteria after Round 3. In this study, all items met the consensus thresholds at Round 3 (i.e., 30/30 items reached consensus), so a separate Round-4 re-rating was not required.

Student knowledge outcomes

Because the study used a one-group classroom design, the following analyses describe observed score changes over time and should not be interpreted as isolating the causal effect of the application alone. Student knowledge of Bua Kheo Mongkol conservation was assessed using an identical 40-item multiple-choice test administered at three time points: pre-test (T1), post-test immediately after the intervention (T2), and a retention test two weeks later (T3). The instrument was organised into seven domains (D1–D7) aligned with the application's learning targets: Domain 1 covers cultivation/care and environmental conditions; Domain 2 focuses on student participation at school; Domain 3 addresses benefits, threats, wise use, and the overall conservation goal; Domain 4 covers conservation concepts, community participation, and sustainability guidelines; Domain 5 reflects values, attitudes, and awareness-building; Domain 6 covers monitoring/documentation and app use for learning; and Domain 7 focuses on interactive technology (quiz/gamification/AR) and appropriate follow-up actions. Each item was scored dichotomously (1 = correct, 0 = incorrect), and total test performance at each time point was calculated as the percentage correct across all 40 items. Descriptive statistics for each time point are summarised in **Table 4**, and paired comparisons are reported in **Table 5**.

Table 4

Descriptive statistics of student knowledge scores

Timepoint	n	Mean (%)	SD (%)	Min (%)	Max (%)	% ≥ 90%
T1 (Pre-test)	30	81.33	2.25	80.00	90.00	3.33
T2 (Post-test)	30	81.83	2.17	80.00	90.00	3.33
T3 (Retention)	30	82.08	2.08	80.00	90.00	3.33

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Table 5
Paired-samples t-tests of student knowledge scores

Comparison	Mean difference (percentage points)	t(df)	p-value
T2 − T1	+0.50	2.69 (29)	0.0117
T3 − T2	+0.25	1.80 (29)	0.0830
T3 − T1	+0.75	3.53 (29)	0.0014

Note. Scores are reported as percentage correct across the 40-item test. Paired t-tests are two-tailed; df = n − 1. Min/max and % ≥ 90% are computed from student-level scores.

Overall performance was already high at baseline (T1: n = 30, M = 81.33%, SD = 2.25%), leaving limited room for improvement. The mean score increased only slightly at post-test (T2: M = 81.83%, SD = 2.17%) and remained close to that level at the two-week follow-up (T3: M = 82.08%, SD = 2.08%). Thus, the absolute changes were small (+0.50 percentage points from T1 to T2 and +0.75 percentage points from T1 to T3). Across all three time points, the observed score range was narrow (min = 80.00%, max = 90.00%), indicating score compression and limited dispersion. This restricted range suggests a ceiling tendency and reduced sensitivity of the instrument to detect larger observable gains in this sample. The complete student-level T1–T2–T3 percentage dataset is provided in **Table 6 (would appear within Appendix)**.

Preliminary assumption checking evaluated the normality of the difference scores between time points. As expected with a narrow, positively skewed score range, the Shapiro-Wilk test indicated that the paired differences deviated significantly from a normal distribution for the T1–T2 comparison ($p < 0.001$). While the paired t-test is generally robust at sample sizes of n = 30, a non-parametric Wilcoxon signed-rank test was also conducted to ensure the validity of the findings. The Wilcoxon test confirmed the statistically significant improvement from T1 to T2 ($Z = 2.45$, $p = 0.014$), aligning with the t-test results.

The T1-T2 comparison showed a statistically significant but very small absolute increase in score ($\Delta = +0.50$ percentage points; $t(29) = 2.69$, $p = 0.0117$). The dispersion of individual gains was modest (SD of differences = 1.02), and the estimated 95% confidence interval for the mean change was [0.12, 0.88] percentage points. The corresponding paired-samples effect size (Cohen's dz = 0.49) should be interpreted cautiously considering the compressed score range and high baseline performance. In practical terms, only 6 students improved, 24 remained unchanged, and none declined between T1 and T2.

For retention, the T2-T3 comparison did not show a statistically significant change ($\Delta = +0.25$ percentage points; $t(29) = 1.80$, $p = 0.083$), indicating that post-test performance was largely maintained rather than meaningfully increased during the follow-up interval. The variability in change was SD (diff) = 0.76, with a 95% confidence interval of [−0.03, 0.53], and an effect size of dz = 0.33. At the individual level, 3 students improved, 27 were unchanged, and none declined from T2 to T3.

Consistent with this pattern, scores at T3 remained statistically higher than baseline (T1 vs T3: $\Delta = +0.75$ percentage points; $t(29) = 3.53$, $p = 0.0014$). However, this gain remained small in absolute terms. The variability in change was SD (diff) = 1.16, with a 95% confidence interval of [0.31, 1.19], and dz = 0.65. Between T1 and T3, 9 students improved, 21 were unchanged, and none declined, suggesting that the modest observed gain was sustained at short-term follow-up rather than substantially extended.

Post-Intervention Student Feedback

Students' post-intervention feedback on the learning experience was collected using a 10-item questionnaire rated on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). The items captured multiple aspects of student experience, including usability (Q1–Q2), engagement and motivation (Q3, Q8), perceived learning support (Q4–Q6), local relevance (Q7), perceived transfer (Q9), and overall satisfaction (Q10). Item-level response distributions and descriptive statistics are summarised in **Table 7**.

The item-level responses were generally positive. Across all items, students selected only "3", "4", or "5", with many responses concentrated at "4" and "5", indicating a positively skewed distribution. Item means ranged from 3.90 to 4.13, suggesting favorable immediate reactions to the intervention across usability, engagement, learning support, local relevance, perceived transfer, and overall satisfaction. The highest-rated items were ease of use (Q1) and overall satisfaction (Q10), whereas the lowest-rated items—though still positive—were alignment of quizzes/exercises with learning content (Q6) and perceived ability to apply learning to real-life conservation actions (Q9). These patterns are interpreted descriptively at the item level and suggest that students generally responded positively to the learning experience, while indicating somewhat weaker endorsement for transfer beyond the immediate classroom context.

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Table 7
Distribution and descriptive statistics of post-intervention student feedback

Item	Questions	Mean	SD	% Agree (4–5)
Q1	The application was easy to use.	4.13	0.51	93.33
Q2	The instructions in the application were clear.	4.03	0.49	90.00
Q3	The learning activities in the application were interesting.	4.03	0.41	93.33
Q4	The content helped me understand Bua Kheo Mongkol conservation.	3.93	0.45	86.67
Q5	The pictures, videos, or animations helped me learn.	4.03	0.49	90.00
Q6	The quizzes or exercises matched what I learned in the application.	3.90	0.48	83.33
Q7	The app helps me understand why Bua Kheo Mongkol is important in our local area.	4.03	0.41	93.33
Q8	I felt motivated to learn and complete the activities.	4.03	0.49	90.00
Q9	I can apply what I learned to real-life conservation actions.	3.90	0.40	86.67
Q10	Overall, I am satisfied with the application.	4.10	0.48	93.33

Internal consistency was examined for transparency; however, the resulting Cronbach's alpha was low in this sample ($\alpha = 0.12$). Accordingly, the questionnaire is not interpreted here as a robust unified scale. Instead, the 10 items are treated as descriptive post-intervention student feedback on specific aspects of the learning experience. For this reason, the results are interpreted primarily at the item level and are used as supplementary evidence alongside the knowledge outcomes, rather than as strong psychometric evidence of a single latent construct.

DISCUSSION

Interpretation of findings

This study provides preliminary classroom-based evidence that the technology-supported instructional sequence was associated with modest conservation knowledge gains about Bua Kheo Mongkol among Grade 5 students. Baseline knowledge was already high, and the observed score changes were small in absolute terms, with performance increasing from 81.33% at T1 to 81.83% at T2 and remaining at 82.08% at T3 (Ibrahim et al., 2024). Given the narrow score range and the discrete scoring steps of the fixed-length multiple-choice test, these changes are best interpreted as modest improvement and short-term maintenance, rather than large educational effects (Webb, 2026). Under the classroom conditions studied here, the intervention appears to have shown preliminary promise, but the design does not allow the observed changes to be attributed confidently to any single feature of the sequence.

The post-intervention student feedback also suggests that the instructional sequence was acceptable and positively received by students, particularly in relation to ease of use, engagement, and local relevance (Novianti et al., 2023). Because the questionnaire is interpreted descriptively at the item level rather than as a robust unified scale, these results should be read as supplementary student reactions rather than strong measurement evidence (Timonen et al., 2024). Even so, the pattern of responses indicates that students generally responded favorably to the learning experience under the observed classroom conditions.

An important feature of the intervention was its effort to situate conservation learning within a locally meaningful context. The positive descriptive responses on local relevance are consistent with the rationale that place-based and culturally grounded content may help make environmental topics more understandable and personally meaningful for young learners (Sugiarto et al., 2023). Likewise, AR-supported visualization, narrative framing, and gamified activities may have contributed to the accessibility and structure of the learning sequence. However, because the intervention also included teacher guidance, worksheets, partner discussion, reflection, and local observation, the present study cannot isolate the independent contribution of AR, gamification, or any other single component. The findings are therefore most appropriately interpreted as reflecting the combined classroom implementation rather than the isolated effect of the application itself.

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It is also noteworthy that the lowest—though still positive—feedback was associated with transfer/application and alignment of quizzes or exercises with learning content. This suggests that future versions of the instructional sequence could strengthen the connection between in-class learning and concrete, age-appropriate conservation actions. In practical terms, the present findings suggest that the intervention was feasible and acceptable as a classroom supplement, while also indicating that stronger learning-to-action links may require more explicit teacher-guided follow-up beyond the app-based activities.

Limitations of the study

Several limitations constrain interpretation. First, the study employed a one-group pretest-posttest design without a comparison group, which limits causal interpretation. Although modest score increases were observed over time, these changes cannot be attributed confidently to the intervention alone because alternative explanations remain possible, including testing or practice effects, novelty effects associated with technology use, teacher facilitation, classroom context, and Hawthorne-type participation effects. Second, the same knowledge test form was administered at T1, T2, and T3. Although this supported direct comparison of performance across time, repeated exposure to the same items may also have increased familiarity and contributed to small score gains independent of the intervention itself. Third, baseline knowledge was relatively high and score variability was limited, suggesting a restricted range and ceiling tendency, which reduces sensitivity to detect larger observable gains. Fourth, the post-intervention questionnaire yielded positively skewed responses and low internal consistency in this sample; accordingly, these data are interpreted only as descriptive item-level student feedback rather than as strong scale-based evidence. Finally, although the intervention included practical conservation-oriented activities and the questionnaire captured perceived transfer, the study did not directly measure long-term conservation behavior; therefore, conclusions should remain limited to knowledge outcomes and descriptive student feedback rather than verified behavioral change (Jordan et al., 2016; Hale et al., 2021).

Future research recommendations

Future research should strengthen causal claims by using a comparison group (e.g., traditional instruction or a non-AR/gamified version) and, where feasible, random assignment at the class or school level. Component analyses are recommended to determine the relative contribution of key design elements (e.g., AR exploration vs gamified quizzes vs narrative modules), which is important given that prior studies highlight distinct mechanisms through which AR and gamification may influence engagement and learning (Shihab et al., 2023; Öztürk, 2023; Lim et al., 2024). Studies should also include broader samples and contexts with lower baseline familiarity to reduce ceiling effects and improve sensitivity. Finally, longer follow-up periods and additional outcomes—such as conservation attitudes, structured behavioral indicators, or teacher-observed conservation actions—would help determine whether short-term gains and positive user experience translate into sustained conservation practices (Jordan et al., 2016; Hale et al., 2021).

CONCLUSION

This study provides preliminary classroom-based evidence that a technology-supported instructional sequence centered on Bua Kheo Mongkol conservation was associated with modest short-term gains in conservation knowledge among Grade 5 students. Using a one-group pretest-posttest design with a two-week retention test, student knowledge scores increased slightly after the intervention and remained close to that level at short-term follow-up. In addition, item-level post-intervention student feedback was generally positive, particularly in relation to ease of use, engagement, and local relevance. These feedback results are interpreted descriptively and suggest that the learning sequence was acceptable and feasible for the target age group under the observed classroom conditions.

The main contribution of this work is the presentation of a context-specific and culturally grounded design approach for primary conservation learning. By combining app-based activities with teacher-guided classroom tasks and locally meaningful content, the intervention offers a practical example of how interactive technology may be incorporated into environmental education for young learners. However, given the absence of a comparison group, the compressed score range, the repeated use of the same knowledge test, and the descriptive nature of the student feedback questionnaire, the findings should be interpreted cautiously. Future studies should use stronger comparative designs, broader samples, and longer follow-up periods to determine whether the modest short-term knowledge gains observed here can be replicated and whether they extend to broader attitudinal or behavioral outcomes.

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Ethical statement

This study was conducted in accordance with applicable ethical standards for research involving minors. Ethical approval for the study protocol was obtained from Rajamangala University of Technology Thanyaburi, Thailand. Written informed consent was obtained from parents or legal guardians, and assent was obtained from the participating students prior to data collection. Participation was voluntary, and students were informed that they could withdraw at any time without penalty. All data were anonymized prior to analysis.

Competing interests

The author declares no competing interests.

Author contributions

As a single-author study, the author was responsible for all aspects of the research, including conceptualization, study design, instrument development, data collection, data analysis, interpretation of findings, and manuscript preparation.

Data availability

The data supporting the findings of this study are not publicly available because they involve research data collected from minors and include materials subject to ethical and privacy restrictions. De-identified data may be made available by the author upon reasonable request, subject to institutional and ethical approval requirements.

AI disclosure

No generative artificial intelligence tools were used to generate the study data, conduct the analysis, or produce the scientific conclusions of this research. AI-assisted tools were used only for limited language editing and formatting support during manuscript preparation, with all content reviewed, verified, and approved by the author.

Biographical sketch

Thosporn Sangsawang is a scholar in the Educational Technology and Communications Division, Faculty of Technical Education, Rajamangala University of Technology Thanyaburi, Thailand. His work focuses on educational technology, instructional design, and the use of digital and interactive media to support teaching and learning.

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APPENDIX

Table 2

Result of Round-2 expert rating of the proposed conservation-learning activities

ID	Questions	Mean	SD	CV	Median	IQR
A1	Students use the app care guide to cultivate and maintain Bua Kheo Mongkol; submit a weekly care log.	4.00	0.8660254038	21.65%	4	2
A2	Students plant Bua Kheo Mongkol using in-app steps; upload a photo + note.	3.67	0.8660254038	23.62%	3	1
A3	Students learn sustainable lotus by-products via the app; complete a quiz + labelled example.	3.11	0.3333333333	10.71%	3	0
A4	Students create lotus-themed art using app prompts; add a short conservation message.	4.00	0.8660254038	21.65%	4	2
A5	Students use an in-app rubric to check garden care; submit a weekly checklist.	3.67	0.7071067812	19.28%	4	1
A6	Students use app prompts to spot plant parts/signs/messages; submit notes or photos.	3.78	0.6666666667	17.65%	4	1
A7	Students learn responsible harvesting via the app; submit a model/drawing with caption.	3.89	0.78173596	20.10%	4	1
A8	Students design eco-packaging using app examples; submit design + brief rationale.	4.00	0.7071067812	17.68%	4	0
A9	Students learn composting via the app and practise if feasible; submit a steps chart.	3.11	0.3333333333	10.71%	3	0
A10	Students journal the lotus ecosystem role using app prompts; submit a short entry.	3.78	0.8333333333	22.06%	4	1
C11	Students link local stories to conservation using the app; write one takeaway.	3.78	0.8333333333	22.06%	4	1
C12	Students build a model/diorama using app templates; label key elements/threats.	3.89	0.78173596	20.10%	4	1
C13	Students create traditional-style conservation art using app themes; add a slogan.	4.00	0.7071067812	17.68%	4	0
C14	Students learn about a local conservationist with app prompts; present 3 takeaways.	3.11	0.3333333333	10.71%	3	0
C15	Students perform a song/movement guided by the app; state the message in 1 sentence.	3.67	0.8660254038	23.62%	3	1
T16	Students complete app modules/mini-games; finish built-in checks.	4.00	1	25.00%	4	2
T17	Students use app AR to explore virtually; submit 3 observations + 1 action.	3.89	1.054092553	27.11%	4	2
T18	Students record a short conservation video using app prompts; include 1 action.	4.00	0.8660254038	21.65%	4	2
T19	Students play a conservation quiz and review; write 1 corrected misconception.	4.00	0.7071067812	17.68%	4	0
T20	Students design a digital poster using app facts; include 1 threat + 1 solution.	3.67	0.8660254038	23.62%	3	1
P21	Students solve app scenarios; submit a simple problem–cause–solution plan.	3.67	0.8660254038	23.62%	3	1
P22	Students discuss use vs conservation with app prompts; write class conservation rules.	3.11	0.3333333333	10.71%	3	0
P23	Students role-play stakeholders using app cards; list actions that protect the ecosystem.	4.22	0.6666666667	15.79%	4	1

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ID	Questions	Mean	SD	CV	Median	IQR
P24	Students design an eco-friendly school idea using app checklist; show 3 features.	4.00	0.8660254038	21.65%	4	2
P25	Students write weekly reflections (app/website); include 1 action + 1 improvement goal.	4.33	0.8660254038	19.99%	5	1
CC26	Students join a clean-up with app safety tips; report waste removed + why it matters.	4.00	0.7071067812	17.68%	4	0
CC27	Students adopt a plant/tree using app checklist; track care/growth.	3.89	0.9279607271	23.86%	4	2
CC28	Students create an eco-campaign using app facts; propose 1 measurable school rule.	4.00	0.8660254038	21.65%	4	2
CC29	Students join a parent–student workshop using the app; commit to 1 action and report back.	3.78	0.8333333333	22.06%	4	1
CC30	Students teach peers using simplified app activities; complete a short quiz/worksheet.	4.00	0.8660254038	21.65%	4	2

Table 3

Result of Round-3 expert re-rating and consensus decision for conservation initiatives for Bua Kheo Mongkol

ID	Questions	Mean	SD	CV	Median	IQR	Consensus
A1	Students use the app care guide to cultivate and maintain Bua Kheo Mongkol; submit a weekly care log.	4.33	0.8660254038	19.99%	5	1	Yes
A2	Students plant Bua Kheo Mongkol using in-app steps; upload a photo + note.	4.11	0.78173596	19.02%	4	1	Yes
A3	Students learn sustainable lotus by-products via the app; complete a quiz + labelled example.	4.33	0.8660254038	19.99%	5	1	Yes
A4	Students create lotus-themed art using app prompts; add a short conservation message.	4.11	0.78173596	19.02%	4	1	Yes
A5	Students use an in-app rubric to check garden care; submit a weekly checklist.	4.00	0.7071067812	17.68%	4	0	Yes
A6	Students use app prompts to spot plant parts/signs/messages; submit notes or photos.	4.11	0.3333333333	8.11%	4	0	Yes
A7	Students learn responsible harvesting via the app; submit a model/drawing with caption.	4.00	0.7071067812	17.68%	4	0	Yes
A8	Students design eco-packaging using app examples; submit design + brief rationale.	4.11	0.78173596	19.02%	4	1	Yes
A9	Students learn composting via the app and practise if feasible; submit a steps chart.	4.00	0.7071067812	17.68%	4	0	Yes
A10	Students journal the lotus ecosystem role using app prompts; submit a short entry.	4.11	0.78173596	19.02%	4	1	Yes
C11	Students link local stories to conservation using the app; write one takeaway.	4.00	0.7071067812	17.68%	4	0	Yes
C12	Students build a model/diorama using app templates; label key elements/threats.	4.11	0.6009252126	14.62%	4	0	Yes
C13	Students create traditional-style conservation art using app themes; add a slogan.	4.11	0.78173596	19.02%	4	1	Yes
C14	Students learn about a local conservationist with app prompts; present 3 takeaways.	4.11	0.3333333333	8.11%	4	0	Yes
C15	Students perform a song/movement guided by the app; state the message in 1 sentence.	4.11	0.78173596	19.02%	4	1	Yes
T16	Students complete app modules/mini-games;	4.33	0.8660254038	19.99%	5	1	Yes

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ID	Questions	Mean	SD	CV	Median	IQR	Consensus
	finish built-in checks.						
T17	Students use app AR to explore virtually; submit 3 observations + 1 action.	4.44	0.7264831573	16.35%	5	1	Yes
T18	Students record a short conservation video using app prompts; include 1 action.	4.11	0.78173596	19.02%	4	1	Yes
T19	Students play a conservation quiz and review; write 1 corrected misconception.	4.22	0.4409585518	10.44%	4	0	Yes
T20	Students design a digital poster using app facts; include 1 threat + 1 solution.	4.11	0.78173596	19.02%	4	1	Yes
P21	Students solve app scenarios; submit a simple problem–cause–solution plan.	4.11	0.78173596	19.02%	4	1	Yes
P22	Students discuss use vs conservation with app prompts; write class conservation rules.	4.00	0.7071067812	17.68%	4	0	Yes
P23	Students role-play stakeholders using app cards; list actions that protect the ecosystem.	4.33	0.5	11.54%	4	1	Yes
P24	Students design an eco-friendly school idea using app checklist; show 3 features.	4.11	0.78173596	19.02%	4	1	Yes
P25	Students write weekly reflections (app/website); include 1 action + 1 improvement goal.	4.44	0.7264831573	16.35%	5	1	Yes
CC26	Students join a clean-up with app safety tips; report waste removed + why it matters.	4.11	0.78173596	19.02%	4	1	Yes
CC27	Students adopt a plant/tree using app checklist; track care/growth.	4.11	0.78173596	19.02%	4	1	Yes
CC28	Students create an eco-campaign using app facts; propose 1 measurable school rule.	4.22	0.8333333333	19.74%	4	1	Yes
CC29	Students join a parent–student workshop using the app; commit to 1 action and report back.	4.11	0.78173596	19.02%	4	1	Yes
CC30	Students teach peers using simplified app activities; complete a short quiz/worksheet.	4.11	0.78173596	19.02%	4	1	Yes

Table 6

Complete student-level T1–T2–T3 percentage result

StudentID	T1	T2	T3
S01	80.00%	80.00%	82.50%
S02	80.00%	80.00%	80.00%
S03	80.00%	80.00%	80.00%
S04	80.00%	80.00%	80.00%
S05	82.50%	82.50%	82.50%
S06	82.50%	82.50%	82.50%
S07	85.00%	85.00%	85.00%
S08	80.00%	80.00%	82.50%
S09	80.00%	80.00%	80.00%
S10	80.00%	80.00%	80.00%
S11	80.00%	82.50%	82.50%
S12	80.00%	82.50%	82.50%
S13	82.50%	82.50%	82.50%
S14	82.50%	82.50%	82.50%
S15	82.50%	82.50%	82.50%

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StudentID	T1	T2	T3
S16	80.00%	80.00%	80.00%
S17	80.00%	82.50%	82.50%
S18	80.00%	82.50%	82.50%
S19	80.00%	80.00%	82.50%
S20	80.00%	80.00%	80.00%
S21	85.00%	85.00%	85.00%
S22	90.00%	90.00%	90.00%
S23	80.00%	80.00%	80.00%
S24	82.50%	82.50%	82.50%
S25	80.00%	82.50%	82.50%
S26	82.50%	82.50%	82.50%
S27	80.00%	82.50%	82.50%
S28	82.50%	82.50%	82.50%
S29	80.00%	80.00%	80.00%
S30	80.00%	80.00%	80.00%
Average	81.33%	81.83%	82.08%

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