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Improving Students' Plant Literacy in Plant Classification through Mobile Learning Integrated with Experiential Learning

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ABSTRACT
This study examined the effectiveness of integrating mobile learning with experiential learning in improving high school students' plant literacy in plant classification. Using a quasi-experimental pretest–posttest control group design, 76 tenth-grade students at SMAN 1 Tukdana, Indonesia, were evenly split into experimental and control groups. The experimental group learned through mobile tools such as PlantNet, iNaturalist, Google Lens, LMS, and Digiventory within an experiential learning framework, while the control group received traditional instruction. Plant literacy was assessed using a validated 30-item multiple-choice test covering the nominal, functional, structural, and multidimensional dimensions of plant literacy. Data analysis involved N-Gain, independent t-tests, and Cohen's d. Results showed that the experimental group achieved significantly higher normalized gains (N-Gain = 60.21%) than the control group (21.91%), with a significant difference ($p < 0.05$) and a very large effect size (Cohen's $d = 2.07$). These findings suggest that integrating mobile learning with experiential learning effectively enhances students' plant literacy through active and contextual learning experiences. More importantly, this study contributes to biology education by proposing an instructional mechanism that explains how the pedagogical integration of mobile learning and experiential learning systematically promotes students' progressive development across the four dimensions of plant literacy. This proposed mechanism provides an innovative pedagogical framework for technology-enhanced plant classification and biodiversity education.

INTRODUCTION

Biology education plays an important role in developing students' understanding of living organisms, ecological interactions, and environmental awareness (Pany et al., 2024; Parsley, 2020). Among the core topics in biology, plant classification is fundamental because students are required to identify morphological characteristics, distinguish taxonomic groups, and understand relationships among plant species (Lindemann-Matthies et al., 2024). However, plant classification is often perceived as challenging due to abstract concepts, scientific terminology, and complex morphological observation skills (Ampatzidis & Amprazis, 2026; Krosnick & Moore, 2024). As a result, students tend to rely on rote memorization rather than conceptual reasoning, which may limit meaningful learning and reduce engagement in biology learning (Theobald et al., 2020; Freeman et al., 2014).

Many students still demonstrate limited ability to recognize plant diversity, identify plant structures, and understand the ecological importance of plants in daily life (Park & Kim, 2025; Mu'aziyah et al., 2025; Pany et al., 2024). This issue is closely related to plant literacy, defined as the ability to identify, classify, and interpret plant characteristics and functions (Beasley et al., 2021; Pongsophon & Jituafua, 2021). Low plant literacy is frequently associated with plant awareness disparity (formerly known as plant blindness), in which learners tend to overlook plants and show low engagement with plant-related content (Parsley et al., 2022; Brownlee et al., 2021). Therefore, improving plant literacy is essential to strengthen students' conceptual understanding and environmental awareness (Ampatzidis & Amprazis, 2026).

Conventional biology instruction in plant classification is often dominated by textbook-based explanations and teacher-centered learning, providing limited opportunities for students to directly observe and investigate plant characteristics (Sobah & Wardhani, 2022; Liunokas & Billik, 2022). Such approaches may restrict active student engagement and reduce opportunities to develop observation and classification skills essential for plant literacy (Beasley et al., 2021). Therefore, more contextual and student-centered learning strategies are needed to facilitate meaningful plant learning experiences (Zahroh et al., 2022; Hikmah et al., 2021).

To address these instructional limitations, mobile learning has gained attention as a flexible and student-centered approach in science education (Hidayat et al., 2024; Tavares et al., 2021; Zulfiani et al., 2021). In biology learning, mobile applications support students in exploring plant materials through digital identification tools and interactive resources, enabling more contextual and independent learning experiences (Finger et al., 2022; Wang, 2017). Therefore, integrating mobile learning into plant classification may enhance student engagement and support plant literacy improvement.

Beyond digital accessibility, effective plant learning also requires direct experience and active knowledge construction. Experiential learning emphasizes concrete experience, reflection, conceptualization, and experimentation, enabling students to actively observe and interpret plant characteristics (Finger et al., 2022; Kolb & Kolb, 2009; Kolb, 1984). Therefore, integrating mobile learning with experiential learning may create more meaningful plant learning experiences and strengthen students' understanding of plant concepts.

While mobile learning provides flexible access to digital resources, LMS-based learning materials, and real-time plant identification, technology alone may not be sufficient to develop higher levels of plant literacy (Finger et al., 2022; Tavares et al., 2021). From a theoretical perspective, plant literacy represents the intended learning outcome, whereas experiential learning explains the pedagogical process through which this outcome develops via concrete experience, reflection, conceptualization, and application (Uno & Bybee, 1994; Kolb, 1984). Within this framework, mobile learning complements experiential learning by providing continuous access to LMS-based learning resources, authentic learning materials, and digital plant identification tools that support each stage of the learning cycle. Consequently, integrating mobile learning with experiential learning is expected to promote the progressive development of plant literacy from recognizing plant terminology to applying plant knowledge in broader environmental contexts.

Although previous studies have demonstrated the effectiveness of mobile learning and experiential learning separately in science education (Finger et al., 2022; Tavares et al., 2021; Zulfiani et al., 2021), studies examining their pedagogical integration to promote the progressive development of plant literacy in plant classification remain limited. Therefore, this study aims to examine the effectiveness of mobile learning integrated with experiential learning in enhancing senior high school students' plant literacy in plant classification.

METHOD

Research Design

This study employed a quasi-experimental method using a pretest-posttest control group design to examine the effect of mobile learning integrated with experiential learning on students' plant literacy (Gopalan et al., 2020). The study involved two groups: an experimental group receiving mobile learning integrated with experiential learning and a control group receiving conventional instruction.

Participants and Sampling Technique

The research was conducted at SMAN 1 Tukdana, Indramayu, West Java, Indonesia, from January 15 to April 15, 2026. The participants consisted of 76 tenth-grade students aged approximately 15–16 years, divided equally into an experimental class (n = 38) and a control class (n = 38).

The participants were selected using purposive sampling from ten tenth-grade classes available at the school. Two classes (Grade X3 and Grade X5) were chosen because they had comparable academic characteristics, followed the same biology curriculum, had compatible instructional schedules, and allowed the instructional intervention to be implemented under comparable classroom conditions (Memon et al., 2024). Baseline equivalence between the two classes was further confirmed through comparable pretest scores, indicating similar initial levels of plant literacy prior to the intervention.

Research Instruments

Students' plant literacy was measured using a 30-item multiple-choice test developed based on the four dimensions of plant literacy proposed by Uno and Bybee (1994): nominal literacy, functional literacy, structural literacy, and multidimensional literacy.

The instrument was initially constructed by the researchers as a 50-item multiple-choice test based on the plant literacy framework proposed by Uno and Bybee (1994). The initial instrument subsequently underwent a content validity process involving two experts: a biology education specialist with expertise in pedagogy and a plant biology specialist. The experts assessed the relevance, clarity, and representativeness of each item in relation to the intended plant literacy dimensions. The instrument was revised based on their recommendations before being administered in the pilot test.

Following expert validation and revision, the instrument was administered in a pilot test to evaluate its psychometric properties. Item validity and reliability analyses were subsequently conducted to identify items that met the required measurement criteria. Based on these analyses, the instrument was further refined by retaining valid items while ensuring adequate representation of each plant literacy dimension. The final instrument consisted of 30 multiple-choice items that met the validity criteria and adequately represented the four dimensions of plant literacy. Instrument reliability was assessed using Cronbach's Alpha, yielding a coefficient of 0.90, indicating excellent internal consistency.

Learning Materials and Intervention

The experimental group received instruction through mobile learning integrated with experiential learning over six meetings. The mobile learning environment was supported by digital tools including the Learning Management System (LMS), Google Lens, PlantNet, and Digiventory.

The instructional procedure followed Kolb's experiential learning cycle (Kolb & Kolb, 2009; Kolb, 1984), consisting of Meeting 1: Pretest and introduction to plant classification material, Meeting 2: Concrete experience, Meeting 3: Reflective observation, Meeting 4: Abstract conceptualization, Meeting 5: Active experimentation, Meeting 6: Posttest.

During the intervention, students explored plant characteristics using mobile applications, conducted direct observations, reflected on findings, formulated concepts, and applied classification principles. Meanwhile, the control group received conventional teacher-centered instruction through textbook explanation, teacher presentation, and classroom discussion without mobile-assisted learning activities.

Research Procedure

The research procedure was conducted systematically in several stages. Preparation stage, including instrument development, validity and reliability testing, and preparation of learning materials and digital platforms. Implementation stage, including pretest administration, intervention in both groups, and classroom learning activities according to the assigned treatment. Final stage, including posttest administration, data collection, statistical analysis, and interpretation of results. Plant literacy data were collected from students' pretest and posttest scores.

Data Analysis

Data were analyzed using descriptive and inferential statistics. Descriptive statistics were used to calculate mean scores and standard deviations of pretest and posttest results. Students' improvement in plant literacy was analyzed using the normalized gain (N-Gain) formula to determine learning improvement between pretest and posttest scores (Hosniyah et al., 2023).

Before hypothesis testing, prerequisite analyses were conducted, including a normality test using the Shapiro-Wilk test and a homogeneity test using Levene's test, to determine data distribution and variance equality (Pallant, 2020). Hypothesis testing was conducted using an Independent Sample t-test to examine differences in Gain scores between the experimental and control groups. To determine the practical significance of the intervention, the effect size was calculated using Cohen's d (Elsayir, 2024; Sullivan & Feinn, 2012). All statistical analyses were performed using IBM SPSS Statistics.

Ethical Considerations

Before data collection, permission to conduct the study was obtained from the school administration. Students participated in the study as part of regular classroom learning activities. Participant confidentiality was maintained by anonymizing all collected data and reporting results in aggregate form.

RESULTS AND DISCUSSION

Improvement of Students' Plant Literacy Scores

The descriptive statistics of students' plant literacy scores in both the control and experimental groups are presented in Table 1.

Table 1. Descriptive Statistics of Students' Plant Literacy Pretest and Posttest Scores

Group	n	Pretest (M ± SD)	Posttest (M ± SD)
Control	38	10.66 ± 2.15	15.05 ± 3.06
Experimental	38	10.45 ± 2.88	22.37 ± 2.25

Note: M = Mean; SD = Standard Deviation; Maximum possible score = 30.

Table 1 presents the descriptive statistics of students' plant literacy scores in the control and experimental groups before and after the intervention. The pretest results showed that both groups had comparable initial levels of plant literacy, with mean scores of 10.66 in the control group and 10.45 in the experimental group. This similarity indicates that the two groups started the study with relatively equivalent baseline knowledge of plant classification concepts.

Following the instructional intervention, plant literacy scores increased in both groups. However, the magnitude of improvement differed considerably between groups. The control group showed a moderate increase from 10.66 to 15.05, whereas the experimental group improved from 10.45 to 22.37. The substantially higher posttest score achieved by the experimental group suggests that students who participated in mobile learning integrated with experiential learning demonstrated greater progress in plant literacy than those who received conventional instruction.

Learning Improvement Based on N-Gain Analysis

To evaluate the extent of students' improvement in plant literacy following the instructional intervention, a normalized gain (N-Gain) analysis was conducted using pretest and posttest scores. The results are presented in Table 2.

Table 2. Comparison of N-Gain Scores Between the Control and Experimental Groups

Group	Mean N-Gain (%)	Category
Control	21.91%	Low
Experimental	60.21%	Moderate

Note: N-Gain categories were interpreted according to Hake (1998).

As presented in Table 2, the experimental group achieved a substantially higher mean N-Gain than the control group. Students in the experimental group obtained a mean N-Gain of 60.21%, which was categorized as moderate, whereas the control group achieved 21.91%, categorized as low. The nearly threefold difference in N-Gain scores indicates that students who participated in mobile learning integrated with experiential learning experienced considerably greater improvement in plant literacy than those who received conventional instruction.

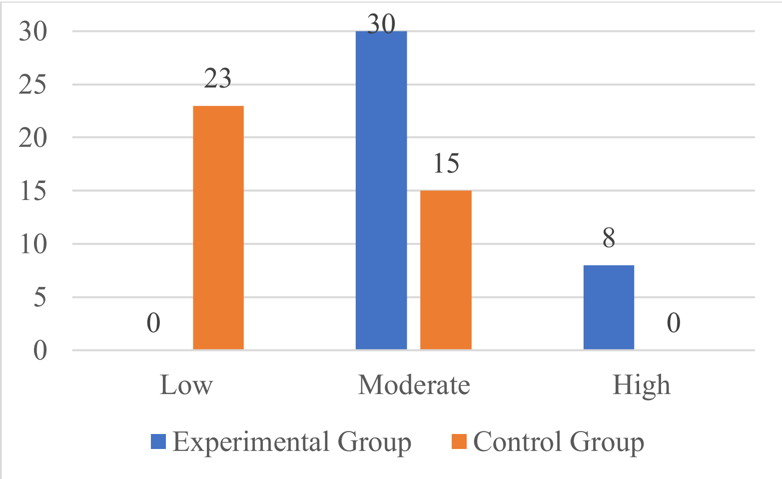

Fig.1. Distribution of students' N-Gain categories in experimental and control groups

Figure 1 further illustrates the distribution of students across the N-Gain categories. Most students in the experimental group achieved moderate improvement (n = 30), while eight students reached the high improvement category and none were classified as low. In contrast, the majority of students in the control group remained in the low improvement category (n = 23), with the remaining students classified as moderate and none achieving high improvement. This distribution indicates that the instructional intervention promoted learning gains across a broader proportion of students rather than benefiting only a small group of high-performing individuals.

Overall, the N-Gain analysis demonstrates that mobile learning integrated with experiential learning was more effective than conventional instruction in improving students' plant literacy. Beyond producing higher average learning gains, the intervention also resulted in a more favorable distribution of learning improvement, suggesting that students with varying levels of prior knowledge benefited from the instructional approach. These findings provide strong evidence that integrating mobile learning with experiential learning effectively facilitates more meaningful and comprehensive development of students' plant literacy in plant classification.

Improvement Across Plant Literacy Dimensions

To obtain a more comprehensive understanding of students' plant literacy development, learning outcomes were further analyzed across the four dimensions of plant literacy proposed by Uno and Bybee (1994), namely nominal, functional, structural, and multidimensional literacy. Pretest, posttest, and normalized gain (N-Gain) scores were calculated for each dimension to identify the aspects of plant literacy most influenced by mobile learning integrated with experiential learning. The results are presented in Table 3.

Table 3. Descriptive Statistics of Pretest, Posttest, and N-Gain Scores Across Plant Literacy Dimensions

Dimension	Group	Pretest (M ± SD)	Posttest (M ± SD)	N-Gain	Category
Nominal	Control	2.42 ± 1.20	3.63 ± 1.48	0.26	Low
	Experimental	2.37 ± 1.30	5.32 ± 1.04	0.64	Moderate
Functional	Control	2.53 ± 1.67	3.95 ± 1.29	0.26	Low
	Experimental	2.95 ± 1.54	6.05 ± 1.29	0.61	Moderate
Structural	Control	2.63 ± 1.44	3.37 ± 1.40	0.17	Low
	Experimental	2.29 ± 1.29	5.11 ± 1.01	0.60	Moderate
Multidimensional	Control	3.08 ± 1.30	4.11 ± 1.45	0.21	Low
	Experimental	2.84 ± 1.53	5.89 ± 1.01	0.59	Moderate

Note: M = Mean; SD = Standard Deviation; N-Gain = Normalized Gain. N-Gain categories were interpreted according to Hake (1998).

As presented in Table 3, students in the experimental group demonstrated consistently greater improvement across all dimensions of plant literacy than those in the control group. The highest N-Gain was observed in nominal literacy (0.64), followed by functional literacy (0.61), whereas structural literacy (0.60) and multidimensional literacy (0.59) also showed moderate improvement. In contrast, all dimensions in the control group remained within the low improvement category, with N-Gain values ranging from 0.17 to 0.26.

The pattern of improvement across the four dimensions suggests that the instructional intervention supported students' plant literacy at progressively more complex levels. The greatest improvement in nominal literacy indicates that students became more proficient in recognizing plant-related terminology, characteristics, and species. The improvement in functional literacy demonstrates enhanced understanding and application of plant classification concepts, while the gains in structural literacy indicate that students became more capable of organizing and relating biological concepts into coherent conceptual frameworks. Furthermore, the improvement in multidimensional literacy suggests that students increasingly connected plant classification knowledge with broader environmental and sustainability issues.

Overall, these findings demonstrate that mobile learning integrated with experiential learning promoted development across all dimensions of plant literacy. Rather than improving only factual knowledge, the intervention facilitated students' progression toward deeper conceptual understanding and contextual application of plant knowledge, indicating a comprehensive enhancement of plant literacy.

Statistical Significance of Learning Improvement

To determine whether the improvement in students' plant literacy differed significantly between the experimental and control groups, assumption testing and hypothesis testing were conducted using students' learning gain scores. The results of the Shapiro–Wilk normality test, Levene's homogeneity of variance test, and Independent Samples t-test are presented in Table 4.

Table 4. Results of Assumption Tests and Independent Samples t-test

Test	Group/Variable	Statistic	Sig.
Shapiro–Wilk	Control Gain Score	0.980	0.709
Shapiro–Wilk	Experimental Gain Score	0.952	0.095
Levene's Test	Gain Score	0.005	0.942
Independent Sample t-test	Gain Score	-9.025	0.000

Note: Data were considered normally distributed and homogeneous when $p > 0.05$.

As presented in Table 4, the learning gain data in both groups satisfied the assumptions required for parametric analysis. The Shapiro–Wilk test indicated that all p-values exceeded 0.05, confirming that the data were normally distributed. In addition, Levene's test showed no significant difference in variance between the groups ($p = 0.942$), indicating that the assumption of homogeneity of variance was met. Based on these results, an Independent Samples *t*-test revealed a statistically significant difference in learning gains between the experimental and control groups, $t(74) = -9.03$, $p < .001$. The mean difference was −7.53 (95% CI [−9.19, −5.86]), confirming that the experimental group achieved significantly greater learning gains than the control group

These findings demonstrate that students who participated in mobile learning integrated with experiential learning achieved significantly greater improvement in plant literacy than those who received conventional instruction. The statistically significant difference between groups suggests that the instructional intervention contributed to the superior learning gains observed in the experimental group. Collectively, these results provide robust statistical evidence supporting the effectiveness of mobile learning integrated with experiential learning in enhancing students' plant literacy in plant classification.

Magnitude of Treatment Effect

To evaluate the practical significance of the instructional intervention beyond statistical significance, an effect size analysis was conducted using Cohen's *d*. The results are presented in Table 5.

Table 5. Effect Size of the Intervention on Students' Plant Literacy

Variable	**Cohen's d**	**Interpretation**
Gain Score	2.07	Very Large Effect

Note: Interpretation of Cohen's d followed Sullivan and Feinn (2012).

As presented in Table 5, the intervention yielded a Cohen's d value of 2.07, indicating a very large effect according to the established interpretation criteria. This result demonstrates a substantial difference in plant literacy improvement between students who participated in mobile learning integrated with experiential learning and those who received conventional instruction.

The magnitude of the effect indicates that the intervention was not only statistically significant but also educationally meaningful. A Cohen's *d* of 2.07 suggests that the observed improvement was substantial and reflected a strong instructional impact on students' learning outcomes. These findings complement the results of the hypothesis testing and N-Gain analysis by providing evidence that the integration of mobile learning and experiential learning produced considerable gains in students' plant literacy, highlighting its potential as an effective instructional approach for teaching plant classification.

Why Did the Intervention Work?

Overall, the findings suggest that the improvement in students' plant literacy was driven by the complementary integration of mobile learning and experiential learning. Mobile learning, through the LMS and digital plant identification tools, provided flexible access to learning resources, scientific information, and authentic plant exploration, while experiential learning transformed these resources into meaningful knowledge through observation, reflection, conceptualization, and application. Consistent with Kolb's experiential learning theory, this integrated learning process supported the progressive development of plant literacy across the four hierarchical dimensions proposed by Uno and Bybee (1994): nominal, functional, structural, and multidimensional literacy. Collectively, these dimensions describe a progressive pathway through which students develop plant literacy, beginning with the recognition of plant terminology and concepts, advancing toward conceptual understanding and knowledge organization, and culminating in the application of plant knowledge to broader environmental and sustainability contexts.

The results showed that nominal literacy exhibited the highest improvement among the four dimensions of plant literacy, with the experimental group achieving a moderate N-Gain of 0.64 compared to 0.26 in the control group. This result indicates that the intervention was particularly effective in strengthening students' ability to recognize plant species, botanical terminology, and basic plant characteristics. The improvement can be explained by integrating mobile-assisted plant identification into the Concrete Experience phase of experiential learning. During field observations, students used Google Lens, PlantNet, and iNaturalist to identify plant species and verify observable characteristics, enabling them to connect authentic plant specimens with scientific names and botanical vocabulary. According to Kolb (1984), learning begins with concrete experience through direct interaction with authentic phenomena, while Uno and Bybee (1994) define nominal literacy as the ability to recognize plant-related terminology and fundamental concepts.

In this context, this finding is consistent with previous studies showing that mobile-assisted plant identification and authentic field learning enhance students' recognition of plant diversity and scientific vocabulary (Coşkunserçe, 2024; Wilsa et al., 2023). However, the present findings suggest that the observed improvement resulted not merely from the use of digital technology but from its integration within the experiential learning cycle, where technology complemented rather than replaced direct observation. Educationally, strengthening students' ability to recognize plant terminology and characteristics provides an essential foundation for subsequent literacy development. Building on this foundation, the intervention also facilitated students' progression toward functional literacy, where recognition evolved into conceptual understanding of plant classification.

As students progressed beyond basic recognition, the intervention also promoted substantial improvement in functional literacy (N-Gain = 0.61), compared with 0.26 in the control group. This progression appears to result from integrating mobile-assisted plant identification into the Reflective Observation phase of experiential learning. Following field observations, students used Google Lens, PlantNet, and iNaturalist to compare plant characteristics, discuss classification criteria, and reflect on similarities and differences among plant groups. These activities enabled students to move beyond recognizing plant features toward understanding classification concepts. Consistent with Kolb's experiential learning theory, reflection transforms concrete experiences into conceptual understanding, while Uno and Bybee (1994) describe functional literacy as the ability to explain and apply scientific concepts.

Similar patterns have been reported in previous studies showing that mobile-assisted plant identification and authentic learning experiences improve students' conceptual understanding of plant classification (Coşkunserçe, 2024; Wilsa et al., 2023). Nevertheless, the present findings suggest that conceptual development resulted not merely from access to digital information but from integrating mobile learning with reflective learning activities. From an instructional perspective, this progression enabled students to move beyond recognizing plant characteristics toward understanding the scientific principles underlying plant classification. This conceptual understanding subsequently provided the basis for organizing relationships among plant groups, which is reflected in the development of structural literacy.

As students developed a deeper conceptual understanding, they also demonstrated considerable improvement in structural literacy, with the experimental group (N-Gain = 0.60) compared to the control group (N-Gain = 0.17). This improvement suggests that mobile learning integrated with experiential learning effectively strengthened students' ability to organize and relate plant classification concepts. During the Abstract Conceptualization phase, students analyzed classification characteristics, compared plant morphology, and synthesized observational data using digital resources from the LMS and plant identification applications. These activities enabled students to identify relationships among plant groups and organize their observations into coherent conceptual frameworks. According to Kolb (1984), abstract conceptualization involves transforming experience into organized knowledge, whereas Uno and Bybee (1994) describe structural literacy as the ability to connect scientific concepts into meaningful conceptual structures.

Comparable evidence has also been reported in previous studies showing that mobile-supported concept organization enhances students' conceptual understanding during authentic science learning (Hwang et al., 2011). Similar evidence was reported by Schneeweiß et al. (2024), who found that structured learning activities promoting connections across biological concepts improved students' ability to organize and explain biological knowledge. Importantly, the present findings suggest that structural literacy is developed not merely through access to digital information but through integrating mobile learning within the experiential learning cycle, enabling students to construct interconnected knowledge from authentic observations. These findings further suggest that the development of structural literacy provided a foundation for students to apply plant classification knowledge in broader environmental contexts, which was reflected in the subsequent development of multidimensional literacy.

Finally, students progressed toward multidimensional literacy to organize plant classification concepts; the intervention further promoted the development of multidimensional literacy, with the experimental group achieving an N-Gain of 0.59 compared to 0.21 in the control group. This finding indicates that students progressed beyond conceptual understanding toward applying plant knowledge in broader environmental and sustainability contexts. During the Active Experimentation phase of experiential learning, students used DigiVentory and the LMS to document plant inventories, communicate their findings, and evaluate the ecological significance of plant diversity within the school environment. These activities encouraged students to apply scientific knowledge to authentic environmental situations while reflecting on biodiversity conservation. Consistent with Kolb (1984), active experimentation enables learners to transfer conceptual understanding into real-world action, whereas Uno and Bybee (1994) define multidimensional literacy as the ability to relate scientific knowledge to wider environmental and societal issues.

These findings also align with previous research showing that mobile-assisted biodiversity learning enhances students' environmental engagement through authentic field experiences (Coşkunserçe, 2024). Similar evidence was reported by Aristeidou and Herodotou (2020), who demonstrated that technology-supported citizen science activities strengthened environmental literacy by connecting scientific learning with authentic environmental investigation. Unlike previous studies, the present findings suggest that multidimensional literacy emerged not simply from learning about environmental issues but from integrating mobile learning with experiential learning, allowing students to investigate, interpret, and communicate evidence from their own surroundings. For biology education, this integrated approach helps students view plant classification as a meaningful tool for understanding biodiversity, supporting conservation awareness, and promoting sustainable environmental decision-making.

Collectively, the findings indicate that the effectiveness of the intervention resulted from the complementary integration of mobile learning and experiential learning rather than from the use of digital technology alone. The LMS and mobile-assisted plant identification tools provided flexible access to learning resources, scientific information, and authentic field activities, while experiential learning transformed these resources into meaningful knowledge through observation, reflection, conceptualization, and application. This complementary process enabled students to progress systematically from recognizing plant terminology to understanding classification concepts, organizing biological knowledge, and applying plant literacy in environmental contexts. These findings extend previous studies emphasizing the benefits of mobile learning for engagement and authentic observation (Tavares et al., 2021; Finger et al., 2022) by demonstrating that technology becomes educationally meaningful when integrated within a pedagogically structured experiential learning cycle. Therefore, meaningful plant literacy development depends not only on access to digital technologies but also on learning experiences that connect scientific knowledge with authentic environmental exploration.

Contrasting Findings and Critical Analysis

Although previous studies have consistently reported the educational potential of mobile learning and experiential learning, both approaches have also been associated with important implementation challenges. Mobile learning does not inherently improve learning outcomes, as its effectiveness depends on appropriate instructional design, while poorly structured digital activities may lead to distraction, cognitive overload, and superficial learning (Talan, 2020; Kang, 2024). Likewise, experiential learning requires sufficient instructional time, teacher readiness, and well-facilitated reflection to ensure that authentic experiences are transformed into meaningful conceptual understanding (Morris, 2020; Chiu, 2022).

The present findings, however, suggest that these limitations were largely mitigated through the systematic integration of mobile learning within the experiential learning cycle. Rather than functioning merely as a platform for accessing digital information, the LMS and mobile-assisted plant identification tools were embedded within each stage of learning to support observation, reflection, conceptualization, and application. Consequently, digital technologies served as cognitive scaffolds that enriched authentic learning experiences instead of becoming isolated instructional media.

This finding provides a broader pedagogical interpretation of mobile learning effectiveness. Instead of suggesting that digital technology alone improves plant literacy, the results indicate that meaningful learning emerged because technology was purposefully aligned with experiential learning processes. Therefore, the educational value of mobile learning appears to depend less on technological availability than on pedagogical integration. This interpretation extends previous studies by proposing that integrating mobile learning with experiential learning constitutes a coherent instructional mechanism capable of supporting the progressive development of plant literacy, a mechanism that is discussed further in the following section.

The findings of this study suggest a learning mechanism that extends previous research on mobile learning and experiential learning. Rather than functioning as independent instructional approaches, their systematic integration appears to support the progressive development of plant literacy through successive stages of learning. Specifically, Concrete Experience predominantly strengthened nominal literacy by enabling students to recognize plant species and botanical terminology through authentic observation. Reflective Observation facilitated the development of functional literacy by encouraging students to interpret classification characteristics and explain scientific concepts. Abstract Conceptualization supported structural literacy by guiding students to organize relationships among plant classification concepts into coherent knowledge structures. Finally, Active Experimentation promoted multidimensional literacy by enabling students to apply plant knowledge to authentic environmental contexts, biodiversity conservation, and sustainability issues.

This sequential relationship suggests that the effectiveness of the intervention did not arise solely from the availability of digital technologies or authentic field experiences, but from the pedagogically structured integration of mobile learning within the experiential learning cycle. Accordingly, the present study proposes that each stage of experiential learning predominantly supports a corresponding dimension of plant literacy, forming a coherent instructional mechanism for literacy development. This conceptual contribution extends existing literature by providing a theoretical explanation of how mobile learning integrated with experiential learning progressively develops plant literacy, thereby offering a pedagogical framework that may guide future biology education and plant literacy interventions.

Educational Implications

The findings of this study have important implications for biology education. Rather than treating plant classification as a topic centered on memorizing taxonomic facts, the results suggest that plant literacy is more effectively developed through a progressive learning process that integrates authentic observation, guided reflection, conceptual organization, and real-world application. By engaging students in authentic plant observation and digital plant identification, this learning approach may also help reduce plant awareness disparity by encouraging learners to recognize the diversity, ecological significance, and everyday relevance of plants within their surrounding environment. The combination of LMS-supported learning with mobile plant identification tools provides teachers with practical opportunities to connect classroom instruction with authentic field experiences while encouraging active student participation. Beyond classroom practice, the proposed learning mechanism offers a pedagogical perspective that may inform the design of technology-supported experiential learning in other areas of biology and environmental education, particularly those requiring students to connect scientific concepts with authentic environmental contexts.

CONCLUSION AND SUGGESTION

This study demonstrates that integrating mobile learning with experiential learning effectively promotes the progressive development of students' plant literacy in plant classification. The experimental group achieved a moderate normalized gain (N-Gain = 60.21%), significantly higher than the control group (21.91%), with a very large effect size (Cohen's d = 2.07), indicating that the intervention produced substantial improvements in students' plant literacy. Rather than improving factual knowledge alone, the intervention supported students' progression across all dimensions of plant literacy, from recognizing plant terminology to applying plant knowledge in broader environmental and sustainability contexts. The findings further suggest that meaningful plant literacy develops through the pedagogical integration of mobile technologies within the experiential learning cycle, where authentic observation, reflection, conceptualization, and application function as complementary learning processes. This proposed learning mechanism provides a conceptual contribution to plant literacy research while also advancing innovative biology instruction by demonstrating how mobile learning and experiential learning can be pedagogically integrated to support meaningful plant learning, particularly in plant classification and biodiversity education. Future research should validate this proposed mechanism across different educational levels, biological topics, and learning contexts, as well as examine its long-term effects on plant literacy, scientific literacy, and environmental literacy.

CONFLICTS OF INTEREST

Authors declare that there is no conflict of interest related to this study. The research was conducted independently without any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, A.S., K., and A.; methodology, A.S., K., and A.; investigation, A.S.; data curation, A.S.; formal analysis, A.S.; visualization, A.S.; writing-original draft preparation, A.S.; writing-review and editing, K. and A.; supervision, K. and A.; project administration, A.S. All authors have read and agreed to the published version of the manuscript.

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DECLARATION OF GENERATIVE AI SOURCES

During the preparation of this manuscript, the authors used Generative AI for language improvement, grammar checking, and refinement of academic writing structure. All generated content was carefully reviewed, revised, and verified by the authors, who take full responsibility for the final content of the manuscript.

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