An ADDIE-Based Development and Evaluation of a Mobile Learning Environment for Enhancing Biology Students' Self-Regulation, Motivation, and Achievement in Benthic Macrofauna Identification

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ABSTRACT

Purpose of the study: This study examines the design, development, implementation, and evaluation of a Mobile Learning Environment (MLE) and its impact on biology students' self-regulation, motivation, and achievement, based on Self-Determination Theory.

Methodology: Guided by the ADDIE model, the study employs a developmental research design using a researcher-developed MLE (Android-based) for species identification. A paired sample t-test was used to analyze significant differences in students' self-regulation, motivation, and achievement. Scope reviews were conducted to identify gaps and solutions through in-depth focus group discussions among biology students.

Main Findings: Results showed significant improvements across all measures (all $p < .001$). Self-regulation increased (autonomous: $d \approx 1.87$; controlled: $d \approx 1.43$). Motivation improved across dimensions: attention (3.62–4.70, $d \approx 1.51$), relevance (3.91–4.79, $d \approx 1.41$), confidence (3.76–4.58, $d \approx 1.31$), and satisfaction (3.75–4.72, $d \approx 1.48$). Achievement showed large gains (common names: $d \approx 1.60$; scientific names: $d \approx 2.20$). The MLE was highly rated in engagement ($M = 4.76$), functionality ($M = 4.50$), and information quality ($M = 4.72$). Psychological need satisfaction was also high (autonomy: $M = 6.51$; competence: $M = 6.60$; relatedness: $M = 5.96$).

Novelty/Originality of this study: The development of a context-specific MLE for species identification of benthic macrofauna integrated in enhanced Teaching–Learning Sequences advances existing knowledge by providing an empirically validated, learner-centered digital tool for species identification with engaging features and contents, addressing gaps in both traditional and mobile-assisted taxonomy learning at the tertiary level.

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1. INTRODUCTION

Rapid advancements in digital technologies have transformed educational systems worldwide [1], [2], reshaping how knowledge is accessed, constructed, and applied [3], [4]. In science education, technological integration is increasingly viewed not merely as an enhancement but as a necessity [5] to address complex learning demands in the twenty-first century [6], [7]. Biology education, in particular, encounters persistent challenges in delivering experiential, field-based, and inquiry-driven instruction, especially in subjects that demand careful observation and practical classification abilities [8], [9]. Traditional instructional approaches—primarily textbooks, printed field guides, and static visual materials often fail to sustain student motivation and engagement, promote deep understanding and accurate observations, or accommodate flexible learning environments [10]-[12].

Among the different domains in biology where these challenges are especially evident is species identification [13]. The ability to correctly identify organisms is foundational to research, ecology, taxonomy, systematic biology, and biodiversity conservation since the discipline of describing and classifying organisms is essential to the life inventory on our planet [14]-[16]. However, species identification has long been considered difficult to teach and learn because it relies on morphological discrimination, memorization of scientific nomenclature, and contextual ecological understanding [17], [18]. Reports indicate declining student interest in taxonomy-related disciplines and limited exposure to authentic field-based identification experiences [8], [19], [20]. These concerns are particularly significant in the study of benthic macrofauna organisms inhabiting the bottom substrates of aquatic ecosystems which serve as important bioindicators for environmental quality assessment [21]-[23]. Despite their ecological importance, instructional resources for benthic macrofauna identification remain limited, fragmented, or overly general [22].

In contemporary education, the rise of mobile technologies offers promising opportunities to address these instructional gaps, as students of today's generation are known as "digital natives" [24], who can, with just a few taps, explore online libraries, digital resources, and educational apps. Mobile learning environments (MLE) enable flexible, portable, and interactive access to educational content, allowing learners to engage with materials beyond classroom boundaries [25]. Prior research Zacharia et al. [26] and Kaliisa & Picard [27], has demonstrated that mobile-assisted learning enhances conceptual understanding, academic achievement, and learner engagement across science disciplines; generally focusing on broad science contexts rather than domain-specific applications such as species identification. Mobile devices have the potential to revolutionize traditional education García-Martínez et al., [28] by allowing students and teachers to create a more interactive, engaging, and autonomous learning experience. This approach removes time and place restrictions and enhances the advantages of experiential learning [29]. For this reason, the use of mobile learning in designing and implementing pedagogies is encouraged and recommended among educators [30] to promote students' academic achievement and significantly increase their motivation [31]. This subsequently made MLE an innovative learning style that will be the next major enabler in this era, taking learning to another level [32], as learning can now be conducted literally in our palms through mobile technologies.

Thus, using a mobile application may provide an avenue for improvements to cope with new demands of the teaching and learning process. A significant benefit of using a mobile application is that learning sustained by students is reduced to independent and self-regulated [33], which can be done even outside the schools. Using MLE, educational programs become responsive, scalable, and dynamic, provide students with personalized guidance [34], and can be a personal learning guide or tool during fieldwork. Moreover, mobile applications have been developed for plant, animal, and insect identification [35]-[37]; however, many existing tools are either globally generalized or designed for citizen science [38], and, therefore lack alignment with formal instructional goals and structured learning requirements at the tertiary level. Few applications are specifically designed to support structured teaching-learning sequences in higher education biology courses.

Beyond cognitive outcomes, contemporary educational research emphasizes the importance of psychological factors in sustaining meaningful learning [39]. Self-Determination Theory Ryan & Deci [40], suggests that learners flourish when their fundamental psychological needs for autonomy, competence, and relatedness are fulfilled. In technology-mediated environments, these needs may be supported through features that allow self-paced exploration (autonomy) [41], immediate feedback and mastery experiences (competence) [42], and collaborative or socially connected activities (relatedness) [43]. Studies investigating mobile learning through the lens of Self-Determination Theory have shown positive effects on motivation and achievement [44], [45]; however, these studies typically examine these variables in isolation and rarely within domain-specific learning contexts of species identification, and current approaches remain insufficient to address both the contextual and psychological dimensions of species identification learning.

Despite the advancements, a significant gap remains at the intersection of mobile learning technology, Self-Determination Theory, and species identification in biology education. Although prior studies have explored mobile learning in science contexts [46]-[48], these studies largely lack context-specific applications for benthic macrofauna identification and are seldom integrated within structured teaching-learning sequences. Furthermore, existing research predominantly emphasizes achievement outcomes, pays limited attention to learners' psychological experiences, and integrates formative evaluation only minimally during implementation [49]. Existing studies have not combined domain-specific content, structured instructional design, and psychological need support all within a single mobile learning environment. Hence, there is a critical need for empirically validated, curriculum-aligned mobile learning environments that simultaneously address the cognitive, motivational, and psychological dimensions of benthic macrofauna species-identification learning in higher education.

To address these identified gaps, this study develops and evaluates a mobile learning environment specifically designed for benthic macrofauna identification among tertiary-level biology students. Guided by the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) instructional design framework [50] and grounded in Self-Determination Theory (SDT) [51], the study integrates the mobile application into enhanced teaching-learning sequences for teaching ecology and taxonomy. The innovation of this research lies in the creation of a context-specific, curriculum-aligned digital tool that simultaneously targets self-regulation, motivation, achievement , and psychological need satisfaction in species identification of benthic macrofauna. By combining developmental research with effectiveness evaluation, this study aims to deliver both a validated instructional product and empirical evidence of its educational impact.

Accordingly, this study aims to design and develop a mobile learning environment for species identification of benthic macrofauna and to determine the effects of the mobile learning environment on students' self-regulation, motivation, and achievement. It further evaluates students' perceptions of the application's engagement, functionality, and information quality, and examines the extent to which the technology supports the psychological needs of autonomy, competence, and relatedness.

2. RESEARCH METHOD

2.1. Design

This study employed a developmental research design guided by the Analysis, Design, Development, Implementation, and Evaluation instructional design model. Developmental research focuses on the systematic design, development, and evaluation of instructional products through iterative refinement and formative feedback [52]. The model ensures a structured yet flexible process for instructional innovation across five phases: Analysis, Design, Development, Implementation, and Evaluation. The study focuses on identifying strengths and areas for improvement, allowing for necessary adjustments to the mobile learning environment before the final version is completed. The ADDIE model was used to guide the MLE's design, development, and implementation into a TLS for species identification of benthic macrofauna.

To examine the effectiveness of the developed mobile learning environment, a one-group pretest–posttest design was used. In this design, participants were assessed before and after exposure to the intervention to determine changes in self-regulation, motivation, and achievement. Although suitable for early-stage instructional development, this design is susceptible to internal validity threats such as testing effects, maturation, novelty effects, and Hawthorne effects [45]. These limitations are acknowledged and discussed in the discussion section.

2.2. Research Environment and Respondent

The study was conducted at a state university in Central Visayas, Philippines that is offering a wide range of undergraduate and graduate programs in various fields, including BS Biology, BSED-Science, and MAEd-Teaching Biology. The participants were twenty-five undergraduate students enrolled in a Bachelor of Science in Biology program, majoring in Ecology. A purposive sampling technique was used to select students with foundational knowledge of species classification and ecological assessment. All participants owned Android mobile devices, ensuring accessibility to the developed application. The study considered students from multiple class sections to gather diverse perspectives on the MLE's engagement design, functionality, and information quality. Table 1 presents the distribution of student respondents.

Table 1. Student-respondents' distribution

Profile		Frequency (n)	Percentage (%)
Gender	Male	5	20.00
	Female	20	80.00
Year Level	Second Year	8	32.00
	Third Year	17	68.00
Age	Under 18	0	0.00
	18-20	18	72.00
	21-23	7	28.00
Devices owned	Mobile Phone	25	100.00
	No Device	0	0.00

The intervention was implemented over three instructional sessions conducted across two consecutive weeks, integrating classroom instruction and mobile application activities. The implementation of MLE was conducted through a blended modality of classroom + app-based activities. A simulated fieldwork for the actual species identification activity was conducted using researcher-collected images of the most common benthic macrofauna found in Bantayan Island, where natural coastal zones are characterized by rocky shores and seagrass beds that support diverse benthic communities.

2.3. Ethical Considerations

Ethical clearance was obtained from the university research ethics committee prior to implementation. Written informed consent was secured from all participants. Students were informed of the voluntary nature of participation, the confidentiality of responses, and the anonymized handling of data. No identifiable personal data was reported.

2.4. Intervention Description

The developed mobile learning environment, BenthixID, is an Android-based application designed to support species identification of benthic macrofauna. Below are its technical specifications:

a. Target platform: Android operating system (version 6.0 and above)
b. Database: Open-source API from iNaturalist (registration performed) and a structured local SQLite database
c. Access mode: Offline core content with optional online updates
d. Search system: Rule-based filtering by taxonomic group and common name
e. Content localization: Filtered content for species (benthic macrofauna) within the Philippines, and Core instructional content focused on benthic macrofauna documented in Bantayan Island, Philippines

The application also contains curated species profiles, morphological descriptions, high-resolution images, taxonomic classification, and ecological notes. The database includes extended entries for global benthic taxa; however, the instructional emphasis was on locally relevant species. The intervention included:

a. Guided orientation to the application
b. Morphological identification exercises
c. Simulated field-based identification tasks
d. Independent practice using in-app quizzes

Students engaged with the application for approximately 60 minutes per session, and usage was monitored through activity completion logs and classroom observation.

2.5. Instruments

Multiple instruments were employed to assess the target variables. Table 2 presents the research instrument matrix.

Table 2. Research Instrument Matrix

Variable	Instrument	Items	Scale	Source	Reliability (α)
Self-Regulation	Learning Self-Regulation Questionnaire	12 (Autonomous=5; Controlled=7)	7-point Likert	Black & Deci (2000)	α = .82–.87
Motivation	Instructional Materials Motivation Survey	10	5-point Likert	Refat et al. (2020)	α = .85
Achievement	Species Identification Test	20	Objective test	Adapted from Lasuen et al. (2023)	KR-20 = .88
App Quality	Mobile Application Rating Scale	10	5-point Likert	Standard MARS tool	α = .90
Psychological Needs	Technology-based Experience of Need Satisfaction	16	7-point Likert	Burnell et al. (2023)	α = .86–.91

The researcher employed multiple data-gathering techniques in accordance with the research objective and design. To identify what instructional materials (IMs) were recently used by biology students in higher education institutions (HEI) for species identification of benthic macrofauna, a literature review was conducted to analyze existing IMs' implementation and perceived effectiveness; and a survey questionnaire were given to students to collect the frequency distribution of the uses of existing MLEs using a 5-point Likert scale, ranging from 'never' to 'always'. To assess students' self-regulation in species identification, the Learning Self-Regulation Questionnaire (SRQ-L) was used, and data were collected using a 7-point Likert scale ranging from 'not at all true' to 'completely true'. It has 12 items with two subscales: autonomous regulation (5 items) and controlled regulation (7 items). The instrument was adapted [53], and reliability was analyzed separately for the two subscales: autonomous regulation and controlled regulation. Next, students' motivation in species identification was assessed through the Instructional Material Motivation Survey (IMMS) and data were collected using a 5-point Likert scale ranging from 'not true' to 'very true.' The 10-item instrument was adapted [54], which was based on four components of motivation: Attention, Relevance, Confidence, and Satisfaction of the ARCS Motivational Model (2 items for attention, 3 for relevance, 2 for confidence, and 3 for satisfaction).

To assess students' achievement in species identification of benthic macrofauna, an identification questionnaire was used to determine the impact of the MLE on students' achievement in this area. The questionnaire consists of 20 items featuring researcher-captured images of essential benthic organisms that students will identify. The instrument was based from related study [55]. The questionnaire was administered to the students before and after the implementation of the MLE. Then, engagement, functionality, and information quality of the MLE app was evaluated using the Mobile Application Rating Scale (MARS) which is a 5-point scale (1-inadequate, 2-poor, 3-acceptable, 4-good, and 5-excellent). Finally, to evaluate students' satisfaction of psychological needs through mobile technology adoption, the Technology-based Experience of Need Satisfaction (TENS-Task) questionnaire was utilized [56], and data were collected using 7-point Likert scale ranging from 'strongly disagree' to 'strongly agree'. The instrument was taken from self-determination theory web site and satisfactory internal consistency was calculated across subscales – autonomy, competence, and relatedness.

2.5. Instrument Adaptation and MLE Validation

All standardized instruments were reviewed and adapted to ensure contextual relevance to mobile-assisted species identification among tertiary biology students. The adaptation process included contextual modification of item wording.

Table 3. Summary of Instrument Adaptation Process

Instrument	Construct Measured	No. of Items	Type of Adaptation	Purpose of Contextualization
Learning Self-Regulation Questionnaire (LSRQ)	Autonomous and controlled regulation	12	Reworded items to reflect mobile-based species identification tasks	To measure self-regulated engagement in identification activities
Instructional Materials Motivation Survey (IMMS)	Attention, Relevance, Confidence, Satisfaction	10	Modified references from "course materials" to "mobile learning environment"	To assess motivation toward the mobile taxonomy module
Species Identification Test	Taxonomic classification accuracy	20	Updated species images and descriptors to benthic macrofauna context	To measure applied identification competence
Mobile Application Rating Scale (MARS – adapted)	Engagement, Functionality, Information quality	10	Simplified technical items; aligned with educational app evaluation	To evaluate perceived quality of the mobile learning tool
Technology-Based Experience of Need Satisfaction (TENS)	Autonomy, Competence, Relatedness	16	Contextual framing specific to species identification activities	To assess psychological need satisfaction in the MLE

Teaching learning sequences for species identification of benthic macrofauna were constructed, integrating the researcher-developed MLE – the BenthixID app. For expert validation, three domain experts two biology educators specializing in taxonomy and species identification, and an educational psychologist with expertise in motivation and self-determination theory were asked to assess, particularly for content validity, clarity, contextual relevance, and how well it represented the taxonomy instruction, field-based application, and psychological need support principles. Their suggested revisions were integrated before the pilot testing.

Table 4. Content Validity of the Developed Mobile Learning Environment (BenthixID App) – Version 1 (v.1) and Version 2 (v.2)

Content Experts	Version 1 (v.1)	Version 2 (v.2)
Expert 1 *(Biology Educator – Taxonomy & Species Identification)*	= 4.84 Improve clarity of diagnostic keys for benthic macrofauna Add labeled morphological diagrams for identification accuracy Refine distractors in identification quizzes for taxonomic precision Ensure alignment between species traits and classification levels	= 4.97 No further revisions recommended

Content Experts	Version 1 (v.1)	Version 2 (v.2)
Expert 2 *(Biology Educator – Field-Based & Applied Ecology)*	= 4.72 Strengthen alignment between learning objectives and performance tasks Improve sequencing of identification modules (simple to complex taxa) Enhance image resolution for field authenticity Add glossary of ecological and taxonomic terms	= 4.89 No further revisions recommended
Expert 3 *(Educational Psychologist – Motivation & SDT)*	= 4.76 Enhance autonomy-supportive language in task instructions Improve competence-based feedback messages after quiz attempts Add collaborative reflection prompt to support relatedness Clarify goal-setting feature to support self-regulation	= 4.92 No further revisions recommended
Overall Mean	= 4.77	= 4.93

The initial evaluation of Version 1 yielded a mean content validity rating of 4.77, indicating high relevance and strong alignment with the principles of taxonomy instruction, field-based application, and psychological need support. Following the incorporation of expert recommendations, Version 2 achieved an improved overall mean of 4.93, reflecting excellent content validity. No further revisions were recommended after the second review. Prior to full deployment, a pilot test was conducted with five non-participating tertiary biology students to evaluate usability, instructional clarity, and learner experience. Participants reported positive perceptions of the app's navigation, structured identification process, and interactive image-based tasks. The diagnostic key was described as helpful in clarifying morphological distinctions among benthic macrofauna. Minor refinements were recommended, including a) expanding explanatory feedback after incorrect responses, b) improving image resolution for selected specimens, c) adding visible progress indicators, d) incorporating glossary support for ecological terminology, and e) enabling flexible navigation across modules. These improvements were put into place before the full launch.

2.6. Research Procedure

The study followed a structured data collection process aligned with the ADDIE instructional design model and the conceptual framework, focusing on the design, implementation, and evaluation of the Mobile Learning Environment (MLE) and the Teaching–Learning Sequence (TLS). In the analysis phase, a baseline assessment of students' self-regulation, motivation, and academic achievement was conducted through pretests. In addition, focus group discussions and a scoping review were undertaken to identify instructional gaps and provide empirical input for the development of the mobile learning application. During the design phase, user interface wireframes were created and the pedagogical structure of the application was aligned with Self-Determination Theory to support students' needs for autonomy, competence, and relatedness. In the development phase, the application was programmed and integrated with curated species data, followed by beta testing to refine functionality and usability. The implementation phase involved students participating in three structured instructional sessions that combined classroom lectures with application-based learning activities. Finally, during the evaluation phase, posttests, surveys, and qualitative feedback were collected to assess the instructional effectiveness of the intervention and the application's overall user experience.

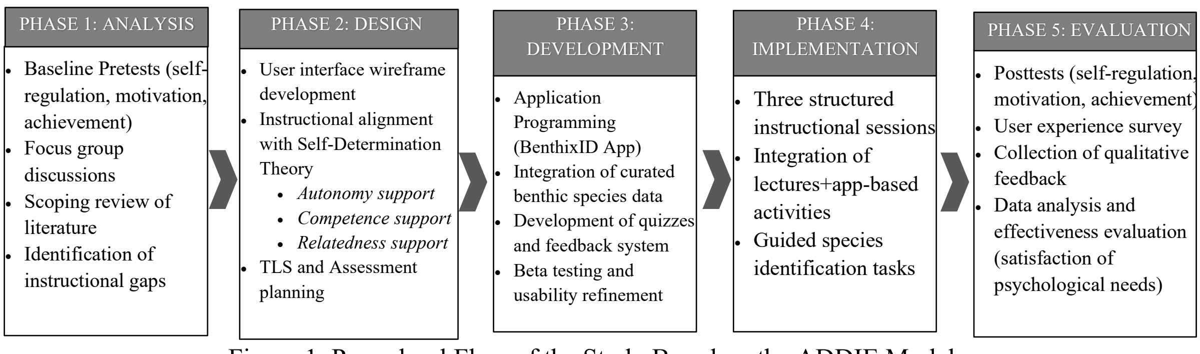

Figure 1. Procedural Flow of the Study Based on the ADDIE Model

2.7. Treatment of the Data

The data analysis techniques used in the study are descriptive and inferential analyses of quantitative data. In descriptive analysis, means and standard deviations were computed for all variables, while in inferential analysis, significant differences were determined between pretest and posttest scores, and paired-samples t-tests were conducted. Normality of difference scores was assessed using the Shapiro–Wilk test. Effect sizes were computed using:

$$d_z = \frac{t}{\sqrt{n}} \qquad \ldots(1)$$

where t is the paired-sample t statistic, and n is the number of participants. Ninety-five percent confidence intervals for mean differences were also reported. All statistical analyses were conducted using Statistical Package for the Social Sciences (SPSS), with a significance level set at 0.05.

3. RESULTS AND DISCUSSION

This study examined the development and evaluation of a mobile learning environment designed to enhance tertiary-level biology students' self-regulation, motivation, and achievement in species identification of benthic macrofauna. Additionally, it discusses students' perceptions of engagement, functionality, and information quality of the MLE, as well as their satisfaction with psychological needs met through technology use. The analyses include tests of significant differences and relationships where appropriate, and the findings are interpreted to emphasize implications for teaching practice and future improvements of the TLS and MLE.

3.1. Review of Existing IMs

To establish the need for developing a context-specific mobile learning environment, the study first examined the instructional materials commonly used by biology students for species identification of benthic macrofauna. Table 5 presents the frequency distribution of materials identified through structured interviews. Printed field guides were used by all respondents (n = 25), making them the most dominant instructional resource. Textbooks (n = 12) and websites (n = 18) were also frequently cited, while mobile applications were used by fewer than half of the participants (n = 12). Tools such as Google Lens (n = 6) and educational videos (n = 6) were used occasionally, whereas posters and electronic books were minimally utilized (n = 1 each).

Table 5. Existing IMs used by respondents in species identification of benthic macrofauna

Instructional Materials	Frequency (n)
Printed Field Guides	25
Google Lens	6
Textbooks (Campbell Textbooks, etc.)	12
Websites (Pinterest, Google, iNaturalist, etc.)	18
Videos (YouTube, etc.)	6
Mobile apps	12
Posters	1
eBooks	1

Number of student-respondents: 25

These findings indicate that traditional printed materials remain the primary resource for species identification despite the availability of digital tools. Their continued use may be attributed to accessibility, portability, and instructor provision. However, reliance on static resources suggests limited interactivity and reduced opportunities for immediate feedback or adaptive learning support. The relatively low use of mobile applications further highlights a gap in structured, curriculum-aligned digital tools specifically designed for benthic macrofauna identification. This gap provided a strong justification for developing the BenthixID mobile learning environment.

3.2. Initial Empirical Investigations of Students' Self-regulation, Motivation, and Achievement

The students' levels of self-regulation, motivation, and achievement before the implementation of the Teaching-Learning Sequences (TLSs) for species identification of benthic macrofauna, integrated with a Mobile Learning Environment (MLE), are presented in Table 6.

Table 6. Students' initial levels of self-regulation, motivation, and achievement

Variable		Measure Used	N	Mean ± SD	Interpretation
Self-regulation		SRQ-L[a]			
	Autonomous		25	5.95 ± 0.42	Strongly Agree
	Controlled		25	4.90 ± 0.95	Agree
Motivation					
	Attention	IMMS[b]	25	3.62 ± 0.78	Good
	Relevance		25	3.91 ± 0.70	Good
	Confidence		25	3.76 ± 0.72	Good
	Satisfaction		25	3.75 ± 0.75	Good
Achievement					

Variable	Measure Used		N	Mean ± SD	Interpretation
	Common name	Species Identification Test[c]	25	14.24 ± 3.60	%EQ = 71.2 → *Good*
	Scientific name		25	8.40 ± 4.28	%EQ = 42.0 → *Fail*

[a]7-point Likert scale, where 1 = *Not at all true* and 7 = *Very true*. Interpretation: 6.21–7.00 (*Strongly Agree*), 5.41–6.20 (*Agree*), 4.61–5.40 (*Somewhat Agree*), 3.81–4.60 (*Neutral*), 3.01–3.80 (*Somewhat Disagree*), 2.21–3.00 (*Disagree*), and 1.00–2.20 (*Strongly Disagree*).
[b]5-point scale, where 1 = *Inadequate* and 5 = *Excellent*. Interpretation: 4.21–5.00 (*Excellent*), 3.41–4.20 (*Good*), 2.61–3.40 (*Acceptable*), 1.81–2.60 (*Poor*), and 1.00–1.80 (*Inadequate*).
[c]Achievement scores were based on a 20-point species identification test and converted to percentage equivalents following the Cebu Technological University (CTU) Student Handbook (2024) grading descriptors: 90–100 = *Excellent*, 80–89 = *Very Good*, 70–79 = *Good*, 60–69 = *Satisfactory*, 50–59 = *Pass*, and below 50 = *Fail*.

3.3. Development of MLE and Enhanced TLSs for Benthic Macrofauna Identification

The primary output of the study was a mobile learning environment specifically designed to assist biology students in identifying species of benthic macrofauna, hereafter referred to as BenthixID. The development of BenthixID was guided by the ADDIE instructional design model, comprising the phases of Analysis, Design, Development, Implementation, and Evaluation, to ensure that the tool met the instructional needs identified in the preliminary stages of the study.

3.3.1. Application Design and Structure

BenthixID is an Android-based application that serves as an interactive platform for learning and conducting species identification of benthic macrofauna. It contains a searchable database of species profiles enriched with high-resolution images, limited morphological descriptions, taxonomic classification, and ecological notes. The app supports both guided and self-paced learning, allowing students to access instructional content and practice identification skills at any time, whether in the classroom or in the field.

3.3.2. Instructional Design Workflow

The development and integration of the Mobile Learning Environment (MLE) followed several systematic phases. In the analysis phase, the content requirements for the MLE were derived through the triangulation of findings from the literature review and student interviews. This process revealed key instructional needs, particularly the lack of interactive, mobile-accessible species databases and the absence of target-specific learning resources for identifying benthic macrofauna. In the design phase, wireframes and navigation maps were created to outline the application's user interface, with emphasis placed on intuitive navigation, high visual clarity, and quick access to morphological identification keys. During the development phase, the application was programmed and populated with a curated species database containing over 29,000 species across major benthic groups, including crustaceans, mollusks, echinoderms, polychaete worms, sponges, and corals. The application also incorporated features such as search filters based on the common names of species, in-app quizzes and games to promote engagement and self-regulation, and autonomous access to detailed species profiles. In the implementation phase, the BenthixID application was incorporated into the three-session Teaching–Learning Sequence (TLS) developed for the study. The TLS served as the pedagogical framework that guided how students were introduced to, practiced using, and applied the MLE in learning activities. Finally, in the evaluation phase, preliminary evaluation data on the application's engagement, functionality, and information quality were collected during the implementation stage.

3.3.3. Key Features of the Mobile Learning Environment

The key features purposively integrated into the Mobile Learning Environment (MLE) were categorized according to engagement, functionality, and information quality to ensure an effective and meaningful learning experience. In terms of engagement, the MLE incorporated gamified learning, which included quizzes, games, and challenges designed to boost student motivation and participation. It also utilized interactive media, featuring high-quality images and educational videos to enhance understanding of concepts. In addition, personalized learning was supported by allowing students to track their progress and revisit topics as needed, while anywhere, anytime access enabled self-paced learning so students could engage with the materials at their convenience. Regarding functionality, the MLE was designed with intuitive navigation, providing simple menus and a logical flow of content to facilitate ease of use. It also included search and filter tools, allowing users to find species using their common names. Furthermore, seamless integration enabled the application to be used alongside lectures, laboratory activities, and fieldwork, while offline access ensured that the Teaching–Learning Sequence (TLS) core resources remained accessible even without an internet connection. In terms of information quality, the instructional material was target-specific, as it was developed explicitly for benthic macrofauna. The content was accurate, containing validated species descriptions and classifications. It also incorporated high-quality visuals, including clear photographs and diagrams, and updated content reflecting the latest taxonomy and ecological data. Finally, the application presented structured information, providing easy-to-digest species profiles that support efficient learning.

3.3.4. MLE Integration into the Teaching-Learning Sequence (TLS)

In the scientific context of learning about benthic organisms, an instructional plan was constructed that integrated the BenthixID app into an enhanced TLSs, which include the following sessions: Introduction to Benthic Macrofauna and the BenthixID App [Session 1], Morphological Features and Identification Keys [Session 2], Application and Field Simulation [Session 3]. These TLSs, produced through a blended modality of classroom and app-based activities, addressed the instructional gaps identified in the analysis phase. MLE was effectively integrated into the TLSs for species identification of benthic macrofauna. Interactive features, functional tools, and high-quality information were combined for the MLE to support both the cognitive and motivational aspects of student learning, in line with the principles of Self-Determination Theory and mobile learning environment. Figure 2 presents the complete TLS framework showing the role of the MLE in each session, while Figure 3 illustrates sample screenshots from the BenthixID interface.

Teaching-Learning Sequence (TLS)

Topic: Species Identification of Benthic Macrofauna using the BenthixID Mobile App
Target Learners: Tertiary Biology Students
Number of Sessions: 3 (1.5–2 hours each)
Mode: Mobile Learning Environment (Blended: classroom + app-based activities)

Session	Learning Objectives	Learning Activities
1 – Introduction to Benthic Macrofauna and the BenthixID App	a. Define benthic macrofauna and explain their ecological role. b. Identify general categories (crustaceans, mollusks, echinoderms). c. Navigate the features of the BenthixID app.	I. Motivation - Short underwater video of benthic life. II. Discussion of benthic macrofauna. III. Demonstration of the BenthixID app. IV. Exploration – Browsing of species profiles in the app. V. Synthesis
2 – Morphological Features and Identification Keys	a. Recognize distinguishing morphological features. b. Apply identification keys to classify organisms. c. Use BenthixID app for guided identification.	I. Review/ brief recap from Session 1. II. Mini-Lecture on morphological features and identification keys of some selected common benthic macrofauna. III. Hands-On (individual) Activity on Species Identification of Benthic Macrofauna using the app + guide keys. IV. Group Work on Cross Checking of identification results.
3 – Application and Field Simulation	a. Apply species identification skills in a simulated field activity. b. Document species findings using scientific protocols. c. Reflect on app usability.	I. Simulation of Fieldwork activity II. Documentation/recording of species names, features, and ecological habitats. III. Presentation of at least two groups to present their findings. IV. Reflection: Student feedback.

Figure 2. The TLS Framework

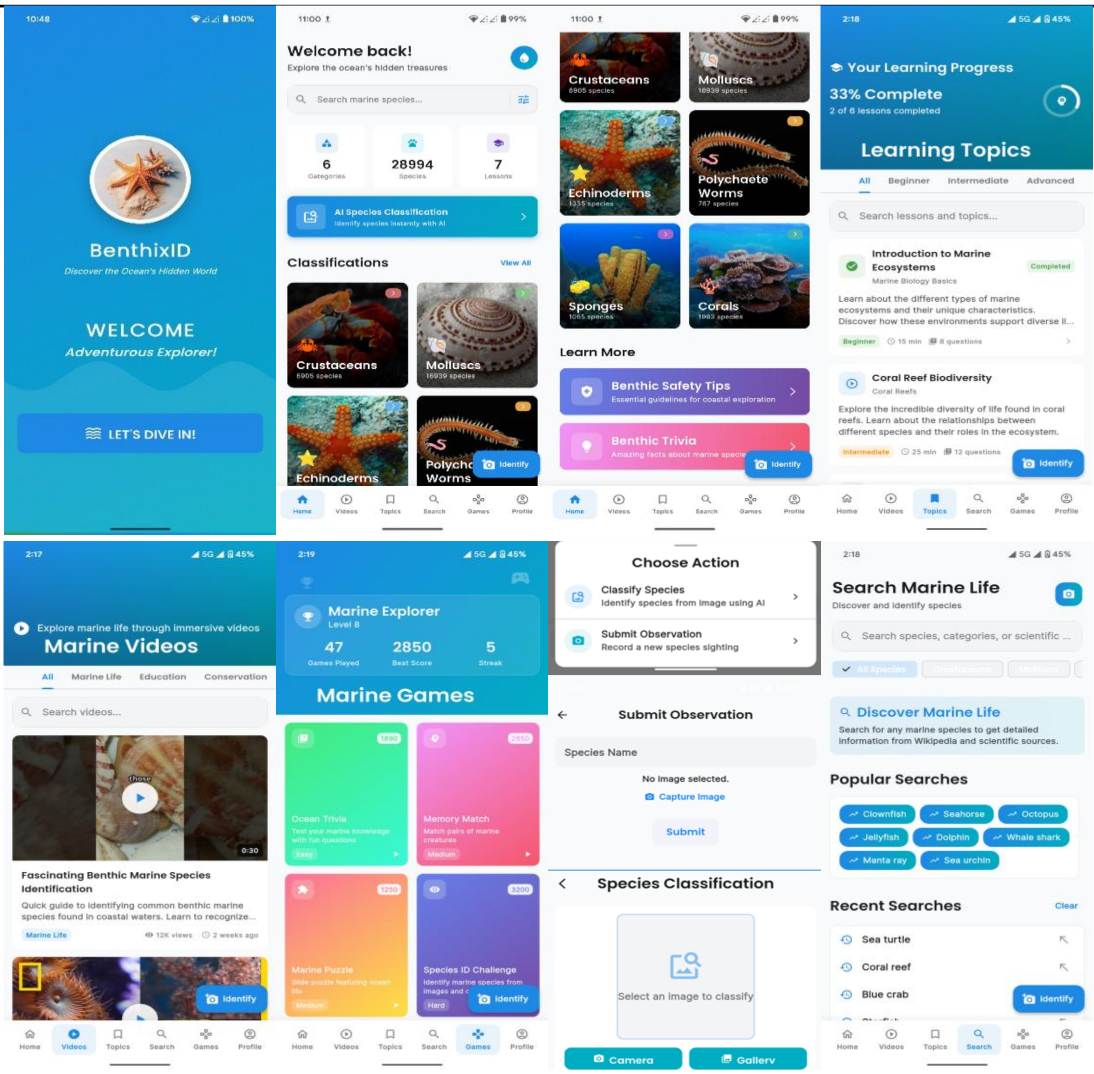

Figure 3. Screenshots of BenthixID App

3.4. Final Investigations of Students' Self-regulation, Motivation, and Achievement

After the implementation of the Teaching-Learning Sequences (TLSs) integrated with a Mobile Learning Environment (MLE), the students' level of self-regulation, motivation, and achievement in species identification of benthic macrofauna were investigated. See Table 7.

Table 7. Students' Final Levels of Self-regulation, Motivation, and Achievement

Variable		Measure Used	N	Mean ± SD	Interpretation
Self-regulation		SRQ-L[a]			
	Autonomous		25	6.78 ± 0.25	Strongly Agree
	Controlled		25	5.66 ± 0.53	Strongly Agree
Motivation					
	Attention	IMMS[b]	25	4.70 ± 0.38	Excellent
	Relevance		25	4.79 ± 0.34	Excellent
	Confidence		25	4.58 ± 0.40	Excellent
	Satisfaction		25	4.72 ± 0.36	Excellent
Achievement		Species Identification			
	Common name	Test[c]	25	19.60 ± 0.82	%EQ = 98.0 → *Excellent*
	Scientific name		25	15.64 ± 3.58	%EQ = 78.2 → *Good*

The statistical analysis of the post-test results for students' self-regulation, motivation, and achievement in species identification of benthic macrofauna shows that all categories across all variables have a notable increase in level compared to the pre-test results.

3.5. Comparative Report of Initial and Final Investigations

The students' pre-test and post-test results were subjected to a paired sample t-test to determine whether there were significant differences in students' self-regulation, motivation, and achievement before and after the implementation of the MLE. The statistical analysis is presented in Table 8.

Table 8. Pre-test and Post-test Results of Students' Self-regulation, Motivation, and Achievement

Variable	Category	Pre M	Post M	t(24)	Mean Diff (Post−Pre)	95% CI of Mean Diff	(d_z)
Self-regulation	Autonomous	5.95	6.78	-9.33	0.83	[0.65, 1.01]	1.87
Self-regulation	Controlled	4.90	5.66	-7.15	0.76	[0.54, 0.98]	1.43
Motivation	Attention	3.62	4.70	-7.53	1.08	[0.78, 1.38]	1.51
Motivation	Relevance	3.91	4.79	-7.07	0.88	[0.62, 1.14]	1.41
Motivation	Confidence	3.76	4.58	-6.54	0.82	[0.56, 1.08]	1.31
Motivation	Satisfaction	3.75	4.72	-7.38	0.97	[0.70, 1.24]	1.48
Achievement	Common names	14.24	19.60	-8.02	5.36	[3.98, 6.74]	1.60
Achievement	Scientific names	8.40	15.64	-10.99	7.24	[5.88, 8.60]	2.20

** All p-values = < 0.001*

Students demonstrated remarkable progress in identifying benthic macrofauna, especially in their achievement. Paired-samples t-tests were conducted to examine differences in students' self-regulation, motivation, and achievement before and after implementation of the mobile learning environment integrated within the teaching-learning sequence.

For self-regulation, autonomous regulation significantly increased from pretest to posttest (MD = 0.83, 95% CI [0.65, 1.01], t(24) = -9.33, p < .001, d_z = 1.87), indicating a very large improvement in students' internally driven learning behaviors. Controlled regulation also showed a significant increase (MD = 0.76, 95% CI [0.54, 0.98], t(24) = -7.15, p < .001, d_z = 1.43), reflecting substantial growth in externally regulated engagement as well. All motivational components demonstrated statistically significant improvements. Attention increased by 1.08 points on average (95% CI [0.78, 1.38], t(24) = -7.53, p < .001, d_z = 1.51), relevance increased by 0.88 points (95% CI [0.62, 1.14], t(24) = -7.07, p < .001, d_z = 1.41), confidence increased by 0.82 points (95% CI [0.56, 1.08], t(24) = -6.54, p < .001, d_z = 1.31), and satisfaction increased by 0.97 points (95% CI [0.70, 1.24], t(24) = -7.38, p < .001, d_z = 1.48). These results indicate large standardized mean changes across all motivational dimensions. Achievement gains were very substantial. Scores for identifying common names increased by 5.36 points out of 20 (95% CI [3.98, 6.74], t(24) = -8.02, p < .001, d_z = 1.60), while scientific name identification increased by 7.24 points (95% CI [5.88, 8.60], t(24) = -10.99, p < .001, d_z = 2.20). The magnitude of change in scientific name identification was particularly pronounced, reflecting marked improvement in more cognitively demanding taxonomy tasks. The results generally demonstrate statistically significant, large, standardized improvements in self-regulation, motivation, and achievement following the implementation of the mobile learning environment.

3.6. Evaluation of Students' Experiences with the BenthixID MLE for Species Identification

The Mobile Application Rating Scale (MARS) was adopted to evaluate the engagement, functionality, and information quality of the MLE, using a 5-point scale (1 = inadequate, 2 = poor, 3 = acceptable, 4 = good, 5 = excellent). Results are presented in a radar chart shown in Figure 4, which illustrates students' evaluations of the BenthixID mobile app as an MLE for species identification, focusing on engagement, functionality, and information quality. The radar plot indicates that most ratings clustered at the higher end of the scale (4.0–5.0), showing that students generally viewed the MLE as highly effective across the three dimensions, as further presented in Table 8.

Table 8. Students' Rating on the MLE – BenthixID App

Dimension	Mean ± SD	Interpretation
Engagement	4.76 ± 0.38	excellent
Functionality	4.50 ± 0.56	excellent
Information Quality	4.72 ± 0.37	excellent

**Ratings were based on a 5-point Likert scale: 1 = Inadequate, 2 = Poor, 3 = Acceptable, 4 = Good, 5 = Excellent.*

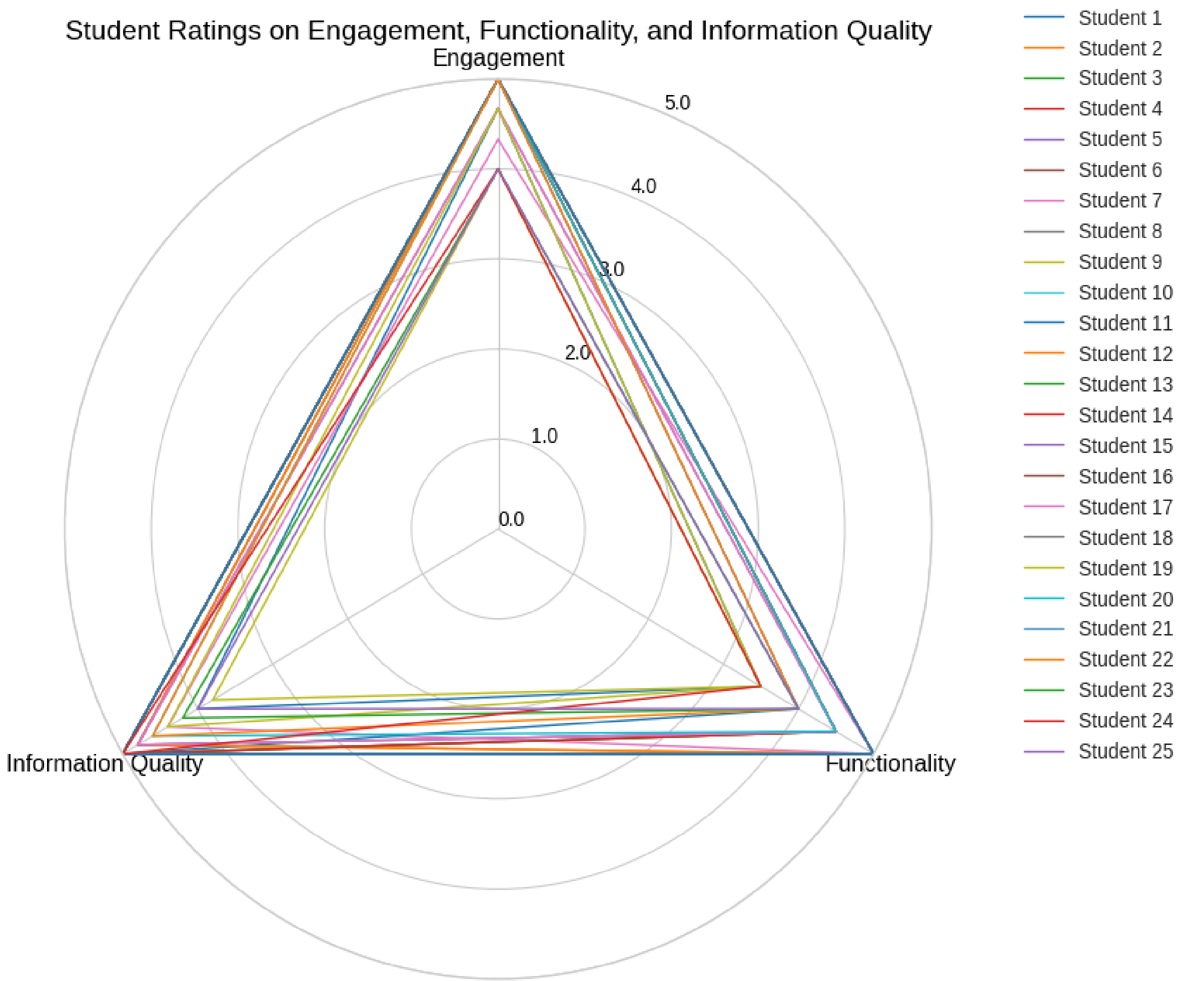

Figure 4. Students' Rating on Engagement, Functionality, and Information Quality of the MLE

3.7. Evaluation of Students' Attainment of Psychological Needs through Technology Adoption

Anchored in Self-Determination Theory, the overall aim of the study was to understand the impact of technology experience on well-being in relation to psychological needs. Technology-based Experience of Need Satisfaction (TENS-Task) questionnaire was utilized to measure autonomy, competence, and relatedness among tertiary-level biology students . In Figure 5, the students' ratings are presented in a bar graph to clearly visualize the extent to which a technology-enabled task impacts their basic psychological needs.

The bar chart in Figure 5 illustrates students' ratings of the three psychological needs autonomy (6.51 ± 0.54), competence (6.60 ± 0.50), and relatedness (5.96 ± 0.62) in the context of adopting the BenthixID mobile learning environment (MLE) for species identification of benthic macrofauna. The implications of these findings are twofold. First, the high ratings in autonomy and competence confirm that the mobile learning environment - the BenthixID App, can effectively enhance students' self-regulation and content mastery, both of which are essential for maintaining long-term engagement. Second, the relatively lower ratings in relatedness underscore the need to incorporate social features, such as discussion forums, peer feedback systems, or collaborative tasks, to fully meet learners' psychological needs. Addressing this aspect may lead to greater satisfaction and better learning outcomes through shared experiences and group problem-solving. The findings indicate statistically significant and large standardized improvements across all measured domains following implementation of the intervention. These results suggest that integrating a structured mobile learning environment within a teaching-learning sequence may positively influence both cognitive and motivational dimensions of taxonomy learning.

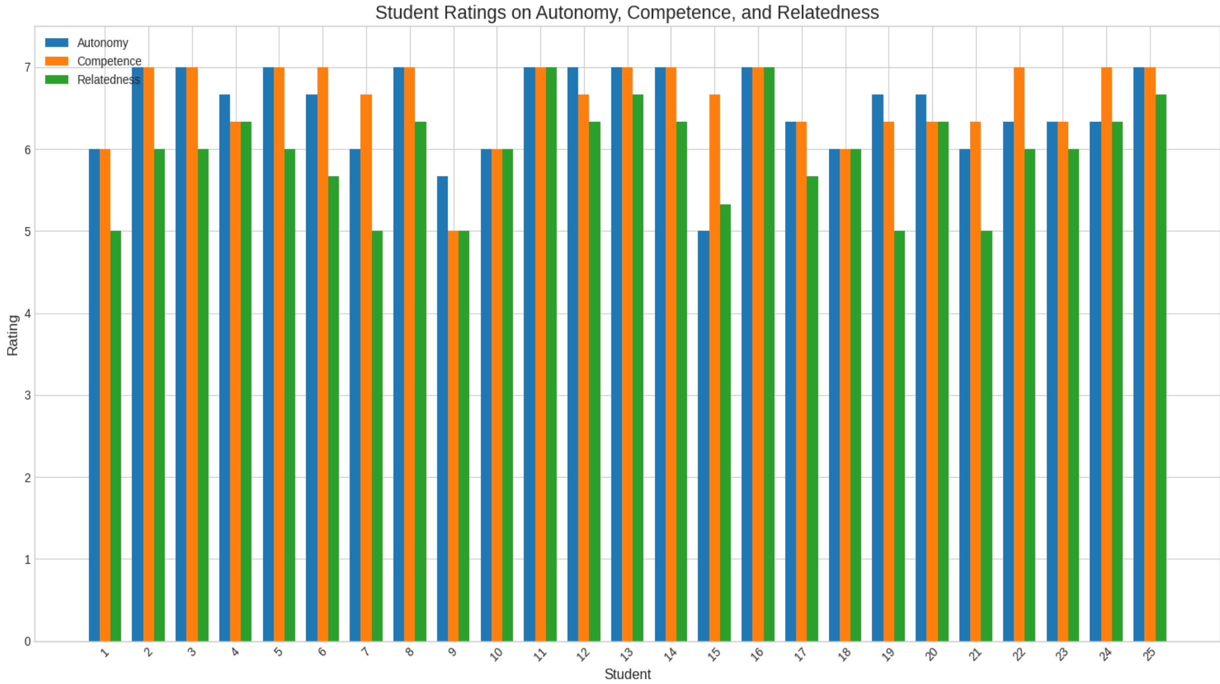

Figure 5. Students' Responses on Technology Adoption in Species Identification

3.8. Self-Regulation and Motivation

The significant increases in autonomous regulation and controlled regulation suggest that the mobile learning environment supported students' capacity to engage in both self-directed and structured learning behaviors. The particularly large standardized mean change observed for autonomous regulation aligns with the core principles of Self-Determination Theory, which posits that environments supporting autonomy enhance internalization and sustained engagement. These findings are consistent with previous research demonstrating that mobile learning tools can foster autonomous motivation and self-regulated learning strategies when designed with interactive and feedback-oriented features [45], [36].

Similarly, improvements across all motivational components attention, relevance, confidence, and satisfaction indicate that the intervention effectively addressed learners' perceived value and engagement with species identification tasks. Prior studies have shown that mobile-assisted learning environments enhance motivation through multimedia support, portability, and contextual application [34]. The present findings extend this evidence by demonstrating that motivation gains can occur within a context-specific taxonomy application integrated into structured instruction rather than through standalone app use.

3.9. Achievement in Species Identification

Substantial improvements were observed in both common and scientific name identification, with the largest standardized change in scientific nomenclature. This is particularly noteworthy, as scientific naming requires higher-order recall, morphological discrimination, and conceptual categorization. These results align with earlier research indicating that mobile-based identification tools can significantly enhance biology students' achievement compared to traditional textbook approaches [34]. The structured integration of the mobile learning environment within guided sessions likely contributed to these gains. Rather than replacing instruction, the application functioned as a scaffolded learning tool embedded within pedagogical sequencing. This integration may explain the great observed improvements while maintaining instructional coherence. However, given the one-group pretest–posttest design, improvements cannot be attributed solely to the intervention without caution. Testing effects, repeated exposure to similar identification items, and novelty effects may have contributed to observed changes. Therefore, findings should be interpreted as evidence of promising effectiveness rather than definitive causal impact.

3.10. Psychological Need Satisfaction

Students reported high levels of autonomy and competence satisfaction when using the application, consistent with Self-Determination Theory's assertion that these needs are central to sustained motivation. The design features—self-paced exploration, immediate feedback through quizzes, and searchable species profiles—likely supported perceptions of mastery and control over learning tasks. Relatedness, while positive, was comparatively lower than autonomy and competence. This pattern mirrors previous findings indicating that mobile learning tools often emphasize individual engagement more strongly than collaborative interaction [33], [44]. The relatively lower relatedness score suggests that future iterations of the application may benefit from incorporating social or collaborative features to enhance peer interaction and shared problem-solving.

This study contributes to the literature in three primary ways. First, it developed a context-specific mobile learning environment explicitly designed for benthic macrofauna identification, a niche yet ecologically significant domain within biology education. Second, it integrated the application within a structured teaching-learning sequence rather than evaluating it as an isolated digital tool. Third, it simultaneously examined self-regulation, motivation, psychological need satisfaction, and achievement within a unified theoretical framework grounded in Self-Determination Theory. Few prior studies have combined these dimensions within a taxonomy-focused intervention at the tertiary level.

From a practical perspective, the findings suggest that mobile learning environments can complement traditional field guides and classroom instruction by providing interactive, portable, and structured support for species identification. Educators in ecology and systematic biology may consider integrating mobile applications within pedagogical sequences rather than treating them as supplementary tools. Theoretically, the study reinforces the applicability of Self-Determination Theory in technology-mediated contexts of biology learning. The alignment between design features and psychological need satisfaction provides further evidence that instructional technologies should be intentionally structured to support autonomy, competence, and relatedness.

Several limitations must be acknowledged. First, the one-group pretest–posttest design limits causal inference due to potential threats to internal validity, including testing effects, maturation, and novelty influence. Second, the sample size was relatively small and drawn from a single institution, limiting generalizability. Third, identical identification items were used in pretest and posttest assessments, which may have contributed to score inflation due to familiarity. Future research should employ randomized controlled or quasi-experimental designs with comparison groups to strengthen causal conclusions. Longitudinal studies may also examine whether gains in species identification and motivation are sustained over time. Additionally, future iterations of the mobile learning environment should explore collaborative features to enhance relatedness and assess their impact on learning outcomes.

4. CONCLUSION

This study developed and evaluated a context-specific mobile learning environment for species identification of benthic macrofauna, integrated within a structured teaching-learning sequence and grounded in Self-Determination Theory. Findings indicate that students demonstrated statistically significant and substantial improvements in self-regulation, motivation, and achievement following the intervention, with particularly strong gains in scientific name identification. Students also rated the application highly for engagement, functionality, and information quality, and reported strong satisfaction with autonomy and competence needs during use. These results suggest that a pedagogically integrated mobile learning environment can serve as a promising instructional complement to traditional taxonomy resources in higher education. Beyond its practical contribution as a validated digital tool, the study advances understanding of how technology design aligned with psychological needs can enhance both cognitive and motivational outcomes in biology learning. Future research employing controlled experimental designs and larger samples is recommended to further validate effectiveness, examine long-term retention, and explore the incorporation of collaborative features to strengthen relatedness support within mobile-assisted taxonomy instruction.

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AUTHOR CONTRIBUTIONS

Conceptualization, J.M.; Methodology, J.M.; Software, J.M.; Validation, J.M. and S.C.; Formal Analysis, J.M.; Investigation, J.M.; Resources, J.M.; Data Curation, J.M. and S.C.; Writing – Original Draft Preparation, J.M.; Writing – Review & Editing, J.M. and S.C.; Visualization, J.M.; Supervision, S.C.

INFORMED CONSENT STATEMENT

All student participants gave informed consent before taking part in the study. They were briefed on the research's purpose, the procedures involved, and their right to withdraw at any point without penalty. Participation was voluntary, and strict confidentiality of the data was ensured.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

During the preparation of this work, the authors used ChatGPT (OpenAI) to assist in refining language, improving clarity of explanations, and organizing sections of the manuscript. After using this tool, the authors carefully reviewed and edited the content as needed and take full responsibility for the accuracy and integrity of the publication.

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