Game On!: Development of a Game-Based Mobile Learning Application in Living Things and Their Environment

Peter Ernie D. Paris and Franz Ian D. Solomon*

College of Education, Faculty, West Visayas State University, Iloilo City, Philippines
Email: peterernie.paris@wvsu.edu.ph (P.E.D.P.); franzian.solomon@wvsu.edu.ph (F.I.D.S.)
*Corresponding author
Manuscript received May 26, 2025; revised July 25, 2025; accepted September 28, 2025; published April 13, 2026

***Abstract*—Mobile game-based learning is increasingly recognized for its potential to enhance academic outcomes, yet its application in addressing specific learning difficulties in Science—particularly Biology—remains limited. This developmental research aimed to develop and evaluate a mobile learning application targeting the least-learned competencies in Grade 7 Living Things and Their Environment (Biology). The Analyze, State the objectives, Select, Modify or Design Materials, Utilize materials, Require learners' response, and Evaluation (ASSURE) instructional design model guided the development process with technology and media integration. Purposively selected learners from public secondary schools; experts in information technology, Biology, and language served as participants of the study. The identified least-learned competencies were: differentiating plant and animal cells; focusing specimens using a compound microscope; predicting the effect of population changes on ecosystems; predicting the impact of abiotic factor changes, and distinguishing sexual and asexual reproduction. In response, four mobile games were developed: *MicroSim* (simulation), *PuzzCell* (puzzle), *ReproDefenders* (adventure/role-playing), and *PredicTerms* (word puzzle). Evaluation results showed high acceptability (*M* = 3.79), with favorable ratings for game usability (3.83), mobility (3.62), gameplay (3.85), and learning content (3.88). Findings suggest that the developed mobile games are suitable for blended learning environments, enabling learners to engage with them. Unlike existing educational mobile games that address general science concepts, this study is novel in its targeted, evidence-based approach which embeds identified least-learned competencies in Biology into purpose-built, curriculum-aligned mobile games developed using the ASSURE model.**

***Keywords*—game-based learning, mobile learning, living things and their environment, developmental research, Analyze, State the objectives, Select, Modify or Design Materials, Utilize materials, Require learners' response, and Evaluation (ASSURE) model**

I. Introduction

What context do you think will be produced if two disparate concepts of "games" and "formal learning" intersect? Incorporating these games in learning have always been known to provide an interesting and engaging learning experiences. This further caters and supports learners in the 21st century with the integration of Information and Communications Technology (ICT) tools.

ICT used in education pertains to the use of information and communication technology in educational setting to improve instruction and delivery of information and there has been also call for the integration of such tools in education, may it be in research or instruction. In the Philippines, in the study of Bonifacio [1], schools need to develop technology use guidelines. These guidelines should focus on pedagogical design for the effective use of ICT, justifying how and why technology is used. Thus, it all boils down to teachers' knowledge, skills, and willingness to employ ICT effectively into the teaching and learning process. If properly used, ICT can create a positive impact on quality education by shifting a teacher-centered classroom to a learner-centered one through interactive approaches. This has been supported by researches focusing on how ICT has greatly improved the quality of education. For instance, ICT integration specifically targets building and development of problem-solving skills, information literacy, and the improvement of the teaching and learning process as a whole [2]. Furthermore, critical thinking, creativity, performance on classroom assessments, motivation and engagement in independent learning have been all shown to be enhanced by ICT-empowered learning environments [3].

Another platform that has gained significant traction is the use of games or digital games through ICT tools. Games are seen to promote learning motivation and engagement, thus, surfacing an appeal for their integration in instruction [4]. Games, in itself, can provide a learning environment that promotes active learning, serve as motivational tools and learning technologies [5]. Using games as a technique in improving students learning is referred to as GBL. There are several areas in the teaching and learning process which GBL has remarkably improved and developed. Its effects on students' cognitive abilities and behavior are well-documented. GBL is seen to have fostered students' motivation and increased participation when it is designed to fit into subject matter instruction [6]. They are also empowered to cultivate their critical thinking and problem-solving skills and creativity through Game-Based Learning (GBL) [7]. Furthermore, game-based collaboration aids competency-based education in improving students' skills, including problem-solving and critical thinking abilities [8].

Specifically, the usage of these games served as a mean to achieve specific objectives, facilitate the study of various subjects, and illustrate certain concepts which can have the potential to enhance the comprehension and retention of academic material [9]. Researchers considered this approach an innovative and effective strategy in delivering instruction and in the attainment of desired learning outcomes by lobbying to various factors known to be crucial in the teaching and learning process. For instance, Saba [10] recognizes that GBL is a functional learning approach and effective method in creating a more enjoyable process of enhancing learning and transferring knowledge through the use of technology better than the traditional approach.

Immersive GBL environments have also been shown to improve students' motivation and engagement, thereby

improving behavior and cognitive learning outcomes [6]. These only shows that GBL can potentially create a platform where students can immerse themselves into learning, critical thinking, creativity, collaboration, and immediate feedback [7]. The integration of game-based techniques with ICT has been increasingly recognized as an effective tool for learning. Digital platforms as ICT tools have been utilized as media of GBL integration. The use of these digital platforms to deliver a playful activity with the goal of attaining target learning objectives and improve teaching and learning is called digital game-based learning. The use of digital games has been of growing interest because of its ability to enhance teaching and learning at all educational levels [5]. The use of digital games has been recognized as an effective ICT tool in increasing students' engagement and motivation in learning [11].

The birth of mobile game-based learning is derived from digital game-based learning. Mobile Game-Based Learning (MGBL) provides an engaging educational experience by combining the elements of mobile learning and game-based learning [12]. Just like game-based learning, MGBL promotes improved motivation and engagement in learning through entertaining techniques and platforms [13]. Using gamification through mobile devices provides a flexible learning experience to learners without the constraints of time and location, while boosting their learning motivation and participation [14]. These tools also facilitate the flexible distribution of educational material, enabling students to participate in learning activities at their convenience, regardless of time or location which overcomes traditional learning limitations and increases student engagement.

As information technology and education continue to merge and evolve, mobile learning, grounded in the principles of GBL, is gaining popularity in the educational sector, however, certain gaps still persist to exist that need to be addressed. One is that the specific game elements that enhance learning, how games capture and maintain learners' attention, and the various learning outcomes that can result from playing games remain areas where consensus has yet to be reached [9]. It shows that researches must be done to further know specific game features supportive of effective learning, helping the attainment of learning outcomes through gameplay. Another notable problem in the implementation of game-based learning is improper design of educational games, together with teachers' reluctance to adopt new methods, and the technological disconnect between students and teachers [7].

It has shown that the current trend in the utilization of GBL became widespread with demonstrated effectiveness in the development of skills and acquisition of knowledge. Coupled with its effectiveness are challenges, limitations, and gaps which could be further given light with empirical evidence and addressed by future studies. While there are abstracts that provide valuable insights into the potential of game-based learning with ICT integration, they do not provide specific guidelines, instructional design, or best practices for the integration and implementation in educational settings. Although GBL demonstrates considerable potential, its efficacy in being integrated in the teaching and learning process could be enhance if it will be used as an approach in teaching least-learned learning competencies. Moreover, integrating instructional objectives within the game's mechanics can aid in game design and enhance conceptual understanding [15].

However, it remains uncertain how effective game-based learning is in fostering real-world problem-solving skills within Science, Technology, Engineering, and Mathematics (STEM) education, highlighting a need for further insight into its influence on particular competencies [16]. Possibly because, according to Osman & Bakar [17], there are factors that hamper in the integration of games into educational setting, one of which is the lack of games designed for instruction tailored for teaching and learning processes in the classroom. Results from these studies also imply that further exploration on GBL custom designed on concepts under specific learning competencies and/ or learning objectives can serve as focus of research studies.

Integrating GBL through ICT tools in the teaching and learning process in a certain learning area for classroom use requires the utilization of an Instructional Design (ID). One of the emerging IDs which had a significant similarity with Gagne's instructional events is the ASSURE (Analyze, State the objectives, Select, Modify or Design Materials, Utilize materials, Require learners' response, and Evaluation) Model. The model uses a six-step process to effectively integrate the use of technology and media into lessons to improve student learning.

With such immense impact of GBL through digital and mobile platforms on learning, many learning areas have embraced the use of such approach to teaching and learning, one of which is Biology. Basic definition of Biology is that it is a field of science that deals with the study of life. It focuses on the study of living organisms or biotic factors, they interaction with each other and to their surrounding environment which are the abiotic factors [18]. By itself, it has a broad range of subdisciplines such as genetics, molecular biology, cellular biology, ecology, and biotechnology among others. Its nature makes it also complex and challenging due to the level of comprehension required to learn its concepts and the difficulties encountered by teachers and students in teaching and learning abstract concepts. With such complexity of its scope, it has been considered as a difficult subject due a number of factors. Topics in this subject contains complex process and conceptual changes that requires deep understanding making it hard to grasp [19]. Synonymous to these learning difficulties are the use of scientific terminologies and the complexity of the topics. Moreover, aside from the nature of the topic, teaching style is also one of the main learning problems which lead to reduced interest and motivation of learners towards the subject [20]. In the local context in the Philippines, the study of Cimer [21] identified five main reasons why students had difficulties learning these topics in Biology, namely, the nature of the topic, teachers' style of teaching biology, students' learning and studying habits, students' negative feelings and attitudes towards the topic, and a lack of resources. In other words, while it is considered as an important field in science and a school subject, its nature makes it also complex and challenging due to the level of comprehension required to learn its concepts and the difficulties encountered by teachers and students in teaching and learning its abstract concepts. In particular, existing

studies on game-based or mobile learning in Biology often address general concepts in science rather than empirically determined least-learned topics. This study addresses this gap by designing, developing, and evaluating a game-based mobile learning application focused on Living Things and Their Environment domain, thereby directly responding to identified least-learned competencies in LTE through a curriculum-aligned and evidence-based approach.

The selection of Living Things and Their Environment as a domain in science as the content focus of the game-based mobile learning application, rather than Chemistry or Physics is grounded on several educational and practical reasons. Even though Chemistry and Physics are, indeed, complicated fundamental sciences, Biology often serves as a foundational subject where concepts from both chemistry and physics are also integrated. Biology's inherent interdisciplinary nature makes it an ideal subject for demonstrating the interconnectedness of scientific disciplines, fostering a more holistic understanding of scientific principles and improving students' ability to apply interdisciplinary skills across various STEM fields [22]. Furthermore, the choice of Biology is strategically linked to student participation and interest. Biology is often perceived by students to be more entertaining and less intimidating than chemistry and physics, which are frequently viewed as more abstract and quantitatively demanding [23]. Our application seeks to foster a greater understanding and enthusiasm for scientific investigation by capitalizing on this inherent interest. Furthermore, an educational approach that includes active learning and problem-based approaches into biology teaching can considerably improve critical thinking and problem-solving abilities [24, 25]. These abilities are critical for addressing challenging scientific challenges across all disciplines, so Biology is a good starting place for building such capabilities in a more accessible and engaging manner.

The existing educational landscape in the Philippines demonstrates a critical need for measures to improve science education, particularly in biology. Despite the emphasis on Biology in the K-12 Enhanced Basic Education Curriculum, a major challenge remains: children consistently show low academic achievement in this subject [26]. This alarming tendency is supported by the Philippines' performance in international evaluations such as the PISA 2018, in which the country scored lowest in Science among all participating countries [27]. These findings highlight a significant gap in the effective delivery and assimilation of biological ideas among Filipino students.

One key factor that contributes to this academic challenge is about knowledge retention and conceptual understanding in Biology. Studies have consistently shown that these two components are essential for efficient subject learning [26]. To solve these inadequacies, creative instructional approaches are required. Research has shown that strategies like the 7Rs of brain-friendly teaching and strategic technology integration can significantly improve students' conceptual grasp of complicated biological topics like photosynthesis and cellular respiration [26]. As a result, developing a game-based mobile learning application in Living Things and Their Environment for Grade 7 students is a timely and critical endeavor that directly addresses identified educational needs while also aiming to improve learning outcomes in Philippine science within the Philippine context.

The participating schools in the study were all public secondary schools of the Department of Education in the Schools Division of Iloilo, Iloilo Philippines. During the conduct of the study, the researcher also considered the emergence of the highly contagious COVID-19 which posed unprecedented threats to the established educational setting. Aside from these, the country is also prone to various natural hazards that could lead schools to shift to distance learning modalities. These include typhoons, floods, changes in rainfall patterns, high heat index, and earthquakes. These natural events can cause damage to school infrastructures and houses, disrupt transportation, and pose threats to students' safety even in school. For the Department of Education (DepEd), schools must find ways for learning to continue amidst the threat and uncertainties brought by these biological and natural hazards, while ensuring the health, safety, and well-being of all learners, teachers, and personnel of the Department. DepEd embarked on the development of the Basic Education – Learning Continuity Plan (BE-LCP) to enable learners of Basic Education to continue learning, and for teachers to be able to deliver instruction in a safe work and learning environment, particularly amid the threat of COVID-19 recently [28]. These obliged the DepEd to adopt different Learning Delivery Modalities suggested in the BE-LCP namely, face-to-face, distance learning (Modular distance learning and online distance learning, TV/ Radio-based Instruction), blended learning, and homeschooling. Modular learning is the most widely used modality and it is more operative in the teaching-learning method as equated to usual teaching approaches because in this modular approach, the students learn in their own stride [29]. On the other hand, online learning might have been a sub-optimal substitute for face-to-face instruction, especially so in the absence of universal access to infrastructure (hardware and software) and lack of adequate preparation among teachers and students for the unique demands that online teaching learning posed. With the flexibility and accessibility of learning that ICT tools can provide, most particularly of mobile phones or devices, game-based learning and mobile learning were infused together that lead to the development of a mobile game-based learning application in order to fit into the distance learning modalities.

So to summarize, with such studies supporting the effective role of ICT in the teaching and learning process, presenting the pedagogical significance of game-based learning in promoting students' learning and claiming the difficulties encountered in learning Biology and the concepts in Biology which the students had difficulty in dealing with, this study recognized such needs by incorporating ICT through the use of a game-based mobile learning application through the ASSURE instructional design in Biology, specifically in the Living Things and Their Environment domain of the Junior High School Science curriculum. Furthermore, this study could mitigate the effects of the challenges posed by online and modular distance learning to students through the use of a mobile game-based learning application which would supplement the distance learning modalities used in learning Grade 7 Living Things and their

Environment. The integration of such specific ICT tool would provide learners the opportunity to learn Living Things and Their Environment in a fun, challenging, and self-controlled way.

This study uses Constructivism and Experiential Learning theories to develop a game-based mobile learning application. Constructivism considered learning to be an active, constructive process. Constructivists viewed the learner as an information constructor: individuals actively construct or create their own subjective representations of objective reality [30]. In relation to the theory of constructivism, the development of a mobile game-based learning application using the ASSURE instructional design model promoted the learner's active participation in constructing knowledge by thinking, doing, and interacting with the simulated environment presented through the mobile game-based application. This knowledge construction process had shifted along with the advancement of multimedia, gaming, and Internet technology. With game-based learning, students had to analyze the perceived information and context in the games proactively and then had to apply their existing knowledge and skills to formulate strategies, make decisions, and then examine results.

In relation to this study, experiential learning forms a foundation of game-based learning in which learners' imagination, motivation, and cognition are harnessed by creating a world to explore challenges, achieving defined learning outcomes, reflecting upon their experiences, and creating new knowledge through transforming game experience. Another notable relation between experiential learning and game-based learning is reflection, which leads to the construction of new concepts. The new concepts were tested through active experimentation and as a result, experiential learning became critical in the process of transferring knowledge gained during the game-based learning event. Dewey [31] stated that experiences were a result of the interplay between the present situation and past experiences. Game-based learning must be designed to create interesting experiences for the learners with corresponding learning outcomes. It was therefore suggested that experiential learning could be used as a theoretical foundation for game-based learning theoretical framework behind game-based learning.

The results and findings of this research study could be useful for science teachers and learners in junior high school, particularly those teaching and learning Living Things and Their Environment, respectively. This suggests the possible adoption of the process of developing game-based learning material with the use of digital tools, tailored from the identified learning competencies and content, adapting to the needs of 21st century learners. Consequently, curriculum developers and designers can also take inspiration form the findings of this study to review and make necessary revisions to cater innovations in the teaching and learning of science.

This study aimed to design and develop a game-based mobile-learning application from the least-learned learning competencies of learners and the most difficult competencies to teach by teachers in Grade 7 Living Things and Their Environment. Specifically, this answered the following research questions:

1) What are least-mastered learning competencies in Grade 7 Living Things and Their Environment, as identified by learners?
2) What game-based mobile learning application can be designed and developed from the identified learning needs and gaps of learners in Grade 7 Living Things and Their Environment?
3) What is the acceptability level of the developed mobile game-based learning application as a supplementary learning material, evaluated in terms of Game Usability (GU), Game Mobility (GM), Game Play (GP), and Learning Content (LC)?
4) What are the perceptions and experiences of learners regarding the use of the game-based mobile learning application as a supplementary material for learning Living Things and Their Environment?

The organization of this paper is outlined as follows: The methodology section provides details on research participants, how they were dealt with ethical considerations, research instruments used for data collection, data collection and data analysis procedures, and the use of ASSURE instructional design model. The results and discussion section is subsequently presented, culminating in the conclusion.

II. Materials and Methods

This study which utilized developmental research, aimed to develop and evaluate a mobile game-based learning application based on the learning and teaching difficulties in Grade 7 Living Things and Their Environment (LTE) of the K to 12 Junior High School Science Curriculum. Moreover, this was guided by the ASSURE (Analyze earners, State the objectives, Select, modify or design media and Materials, Utilize Media and Materials, Require learners' response and participation, and Evaluate) model. The ASSURE model is widely used to integrate technology into teaching. It helps educators design and implement instructional activities that leverage digital tools to enhance learning outcomes. To achieve, quantitative methods, (including descriptive statistics through mean percentage scores, means, standard deviation, and frequency count) used in identifying least-learned competencies and evaluating the learning application's acceptability, and qualitative methods such as semantic thematic analysis of open-ended questionnaire responses were utilized.

Developmental research is a systematic approach to the design, development, and evaluation of instructional and non-instructional products and instruments, as conceptualized by Richey and Klein [32]. This methodology is primarily concerned with the establishment of empirical foundations for the development of these tools and models, thereby guaranteeing their efficacy and efficiency in real-world applications [33]. This methodology also emphasizes an iterative process where initial design principles are continuously refined based on feedback and real-world application. It is also defined by Wang and Hannafin [34], "it is a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real world settings, and leading to contextually-sensitive design principles and theories". Furthermore, according to Klaassen

and Kortland [35], it entails a cyclical process of comprehensive development and assessment, focused on content-specific exemplary teaching-learning sequences.

Specifically, this research is categorized under the Type I developmental research. According to Richey and Klein [32], Type I developmental studies focus on the development of a specific instructional product, program, process, or tool. This type of research reflects an interest in the goal of identifying either general principles or context-driven suggestions. At times, validation of a particular design or developed material or tool is being addressed, thus, evaluation is also part of the process aside from product design and development. Likewise, the purpose of this study to design, develop, and evaluate of a game-based mobile learning application that can be used as a learning material in teaching and learning the Science domain Living Things and Their Environment.

This study was further guided by the ASSURE model. This model, developed by Heinrich *et al.* [36], necessitates that educators remain informed about new and emerging technologies that may prove more effective. It integrates the use of technology and multimedia in planning a lesson to enhance the learning environment [37]. Similarly, this was used in the study to design and develop a game-based mobile learning application as a learning that can make the learning environment more efficient and conducive with the integration of technology.

A. Research Participants

Respondents. Seventy-three Grade 8 students from a public secondary school in the Division of Iloilo where the researcher was teaching served as the respondents of the study. In response to the health-related concerns of the new normal right after the pandemic, the school adopted the modular distance learning modality in which the students were divided into sections based on the barangay where they were residing. This type of sectioning was implemented for the smooth distribution and retrieval of printed modules and students' outputs and the easy monitoring of students by their respective advisers. These participants were from the three barangays nearest to the school and only those whose parents had given their consent to let their children participate were included. Grade 8 learners were chosen to be assessed in determining the least-learned learning competency in Grade 7 LTE domain because the study was conducted during an academic period when current Grade 7 learners had not yet covered this domain in the Grade 7 Science, whereas Grade 8 learners had recently completed it in the previous school year and grade level and could reliably reflect on their experiences with the material.

During the implementation stage, a class of twenty (20) Grade 7 regular class learners was utilized. They were subjected to instruction under a teacher implementer and were given the opportunity to use the developed learning material. Since it was at that time that limited face-to-face learning modality was implemented, a maximum of 20 students were only allowed inside the classroom. Another criterion in selecting these Grade 7 participants was that they must own an android mobile phone. These same twenty (20) Grade 7 learners were also the ones who evaluated the acceptability of the learning material from the perspective of a learner.

Evaluators. The researcher worked collaboratively with 2 Information Technology (IT) faculty, two science/ biology curriculum experts, and one language expert in order to establish the quality of the developed material by serving as validators and evaluators. They selected purposively in a manner considering how their proficiency and expertise would match the different aspects of the material to be evaluated. As validators, they checked the initial protoype prior implementation, and as evaluators, they assess the acceptability of the material. After the first version of the material was developed, it was then subjected to validation by these experts which paved the way for its refinement through their valuable insights and suggestions. Consequently, the enhanced version then, again underwent evaluation with an adapted questionnaire with specific criteria to which the assessment will be based upon. Overall, their comments and suggestions insightfully guided the designing and developing process of the game-based mobile learning application, and even in furthering the extent of its quality as a learning material.

Ethical Considerations. In conducting this study, certain ethical norms were conscientiously considered. The following ethical principles were employed to make sure that research participants were free from any harm: (1) Participants–73 Grade 8 learners, 20 Grade 7 learners, teachers, and experts - were fully informed of the purpose and procedures of the study, which was to design, develop, and evaluate a game-based mobile learning application and were invited to participate voluntarily without pressure or coercion. (2) Anonymity was maintained by assigning unique identifiers to participants and excluding personal details from data analysis and reporting. (3) Prior to data gathering, permits to conduct the study were obtained from the schools division superintendent and school administrators. (4) Consent form and assent form were accomplished by parents and student-participants, respectively. (5) Any data and information provided by the participants were treated with utmost confidentiality, stored securely on password-protected devices, and used exclusively for research purposes, with access restricted to the research team. These measures safeguarded participants from harm and upheld ethical standards throughout the study.

B. Data Gathering Instruments

The following are the different instruments were employed to the participants to gather the needed data necessary towards the development of a game-based mobile learning application in LTE. A summary of these instruments is shown in Table 1.

Grade 7 Living Things and Their Environment (LTE) Competency Test. This 50-item researcher-made multiple-choice instrument covers the twelve learning competencies of Grade 7 Living Things and Their Environment. The instrument was constructed with a Table of Specifications to determine the distribution of the number of items among the learning competencies. The test items underwent face and content validation by university experts. It has undergone pilot-testing in an intact group of regular class students in a secondary school within the same Schools Division to establish its reliability and was determined using Kuder Richardson 20 or KR 20 and indicated an alpha level of 0.89 reliability coefficient, indicating that the test was reliable. This set of students was excluded in the actual

assessment of least-achieved competencies in Grade 7 LTE. From a 60-item multiple choice test, it was trimmed down to 50 items. This occurred because certain items in each competency did not satisfy the specified discriminant coefficient of 0.20 or higher. Moreover, tests that have high internal consistency include elements having a positive relationship with the overall test outcome. Because of the many items and total score distributions, the discrimination index values rarely exceed 0.50 in practice. Item discrimination is considered good if the index exceeds 0.30, acceptable if it is between 0.10 and 0.30, and bad if it is less than 0.10. [38].

Each item is worth one (1) and the test scores gathered from students were analyzed to determine the least-learned learning competencies using frequency and mean percentage scores. The top three learning competencies with the lowest frequency served as the focus of the learning of the games to be included in the mobile application.

Questionnaire on Learners' Mobile Game Type Preference. This researcher-made, administered to the same 73 Grade 8 learners, consisted of one checklist-type item designed to determine possible game types that would guide the researcher in designing the mechanics of the games to be included in the mobile application. Learners were simply asked to identify their top three preferred (3) game types or formats. Game formats used in the questionnaire as options were intersections of most popular games according of Gros [39] and Connolly [40], namely, strategy, puzzles, role playing, action, adventure, simulation, fighting, and sports games.

To establish content validity, the instrument was reviewed by university experts who also validated the other research instruments. Criteria such as relevance to the target learners, clarity of options, comprehensiveness of game types, and alignment with educational game-based learning principles. Feedback included minor suggestions for simplifying language, which were incorporated into the final version. No major revisions were needed. Because the instrument contained only one checklist-type item, internal consistency reliability measures were not applicable. Instead, the study relied on expert validation and face validity to ensure the instrument's reliability and suitability for capturing learners' mobile game type preferences informing the game development process in this developmental study. Frequency counts of selected game types informed the design of the four games.

Game-based Mobile Learning Material Evaluation Form. Adapted from Scepanovic *et al.* [41], this research instrument was used to evaluate the acceptability of the developed material. Two (2) IT faculty, three (3) science curriculum experts, and one language expert used this form to ensure the quality of the developed material by serving as validators and evaluators. Information such as evaluators' name (which they may opted not to write), instructions on how to evaluate, and indicators for the different criteria were included in the instrument. Major criteria namely, Game Usability (7 items), Game Mobility (3 items), Gameplay components (8 items), and Learning Content (4 items) components with specific indicators were rated either as "Very Acceptable (VA) – 4", Acceptable (A) – 3", "Moderately Acceptable (MA) – 2", or "Barely Acceptable (BA) – 1" and were interpreted using mean and standard deviation. Sample items include "Game controls are convenient and flexible and game is adapted to my screen size" (Game Usability); "The game and play sessions can be started quickly." (Game Mobility); "The players are rewarded and rewards are meaningful." (Game Play); and "The game provides learning content." (Learning Content. Open-ended questions were also asked to probe evaluators' perception and experience in using the mobile application and was analyzed using thematic analysis.

Open-ended Questionnaire. This tool collected qualitative data on perceptions and experiences of 20 Grade 7 learners who used the game-based mobile learning application during the implementation phase. The guide included open-ended questions, *"Did you find the mobile learning application useful? Why or why not?"; "Did the mobile learning application helped you in learning Living Things and Their Environment concepts? How?"*; and *"How did you find the following components of the mobile-game-based learning application? What can you say about its illustrations, layout, graphics, and color schemes?"*. The questions were designed based on Kolb's experiential learning theory, emphasizing reflection on learning experiences. The questionnaire was validated by the same expert panel (one Biology educator, one information technology expert, one instructional design expert) for clarity and relevance, with minor revisions to ensure age-appropriate phrasing. Responses were analyzed using semantic thematic analysis [42], focusing on explicit meanings in the data. The analysis followed six steps: (1) data familiarization, (2) generating initial codes, (3) searching for themes (e.g., engagement, content clarity, technical issues), (4) reviewing and refining themes, (5) defining and naming final themes to summarize students' perceptions and experiences and (6) producing the report. This qualitative approach provided insights into the application's impact in a blended learning context.

Table 1. Summary of research instruments

Instrument	Participants	Format	Data Analysis
Grade 7 LTE Competency Test	73 Grade 8 learners	50-item researcher-made multiple-choice test	Frequency, mean percentage scores
Mobile Game Type Preference Questionnaire	73 Grade 8 learners	Single-item checklist (8 options)	Frequency counts
Game-based Mobile Learning Material Evaluation Form	2 IT faculty, 3 Science/Biology Curriculum experts, 1 language experts	22-item Likert scale with 1 open-ended question	Mean, SD, semantic thematic analysis
Open-ended Questionnaire	20 Grade 7 learners	Open-ended questions	Semantic thematic analysis

C. Research Procedure

This developmental research study adhered to a structured methodological framework, guided by the principles of the ASSURE (Analyze the learners, State the objectives, Select, modify, or design media and materials, Utilize media and materials, Require learners' response and participation, and

Evaluate) instructional design model as shown in Fig. 1. The development process was systematically organized into distinct phases: Planning, Design, Validation, Revision, and Implementation, ensuring a rigorous and iterative approach to the creation and evaluation of the mobile game-based learning application.

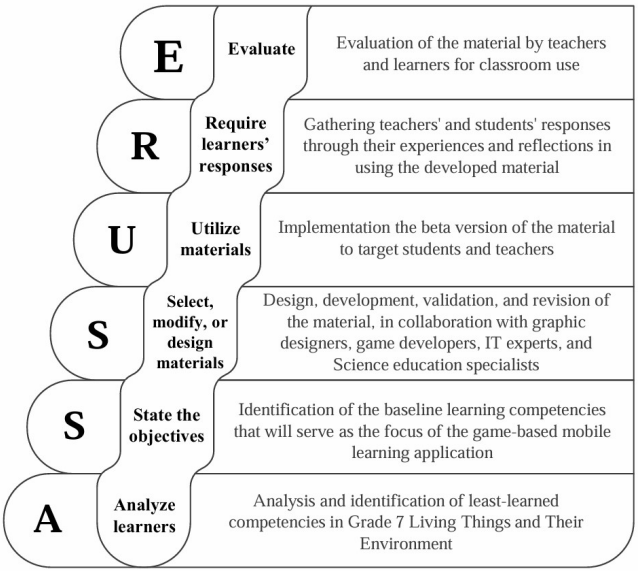

Fig. 1. The diagram of the design, development, evaluation of the game-based mobile learning application guided by the ASSURE model.

Planning Phase. Before conducting the entire data-gathering procedure of the study, a letter of permission was submitted to the Superintendent of the Schools' Division of Iloilo. Included in the letter as a basic requirement was strict compliance with the minimum health and safety protocols during the data gathering to ensure the safety of the students and the teachers. Concurrently, permission letters were dispatched to the principals of the identified schools for pilot testing and subsequent data gathering, accompanied by the requisite approval from the Schools Division Superintendent. A foundational activity within this phase involved a comprehensive analysis and review of the Grade 7 Living Things and Their Environment domain within the Junior High School Science Curriculum. This analysis served as the baseline for the construction of the Grade 7 Living Things and Their Environment Competency Test. The administration of this competency test to students, under the guidance of their respective advisers, facilitated the identification of least-mastered learning competencies. The mean and mean percentage scores derived from this assessment were instrumental in pinpointing the specific learning content to be integrated into the mobile game-based learning application.

Design Phase. Following the identification of critical learning competencies, the design phase commenced with the conceptualization and development of the mobile application. This involved close collaboration with an information technology expert, specifically a mobile application developer/programmer, and a graphic designer. A preliminary paper draft detailing the learning content, design specifications, user interface layout, game mechanics, instructional guidelines, and software requirements was meticulously prepared. This draft was then submitted to the developer/programmer for approval, with careful consideration given to project timelines and the inherent complexity of development. Guidelines for the graphical elements to be incorporated into the mobile application were also suggested by the programmer to the researcher. Key components integrated into the mobile application included a central game menu and comprehensive game instructions. The game menu was designed to host four distinct mobile games; each developed in based on and in direct response to the identified least-learned competencies. The game instructions provided clear guidance on navigating and interacting with the mobile application, including specific directions for each individual game. With the guidance of the researcher and the developer, the graphic designer was responsible for the creation of logos for the individual games and the overall mobile application, as well as the digital rendering of characters, objects, and background visuals. The game developer/programmer undertook the technical development of each game and the overarching mobile application, utilizing appropriate coding languages and software development platforms. This collaborative effort underscored the meticulous approach to material development.

Validation Phase. After synthesizing the parts and parcel of the mobile application, the prototype software of the material was developed. This prototype incorporated all fundamental functions and features envisioned for the mobile game-based application. This version served as the prototype where all the basic functions and features designed for the mobile game-based application were coded and other additional details and revisions suggested by the evaluators such as Biology experts, IT experts, and language experts were incorporated for the improvement of the material prior to implementation. The validation done by the experts and panel members served as bases to further improve the prototype. Their comments, suggestions, and feedbacks were essentially considered in the revision of the developed material for its improvement before its implementation to the target users.

Revision Phase. The insights garnered from the expert validation process were crucial for refining the prototype. All additional details and revisions suggested by the evaluators were meticulously incorporated into the mobile application. This iterative revision process ensured that the developed material was robust, accurate, and aligned with expert recommendations prior to its broader implementation.

Implementation Phase. Subsequent to successful validation and comprehensive revisions, the developed material was prepared for implementation. This phase involved the integration of the mobile application into a regular Grade 7 class, facilitated by a collaborating teacher-implementer. A detailed lesson guide was prepared for the teacher, outlining the effective utilization of the developed mobile application within the curriculum. The researcher worked closely with the teacher to prepare the lesson, which included supplementary instructional materials such as PowerPoint presentations and activity sheets. Key strategies for effectively integrating the mobile learning application into Grade 7 instruction were also identified. A single Grade 7 Living Things and Their Environment teacher, who expressed willingness to participate, was involved in the implementation of the material.

Evaluation Phase. During the implementation, the researcher keenly observed students' engagement with and utilization of the mobile application games. Furthermore, students were invited to share their experiences, reflections, and recommendations through an open-ended questionnaire, providing qualitative insights into their interaction with the learning tool. Following the implementation, the developed material underwent a formal evaluation by both the learners and teachers who had utilized it. This evaluation assessed various aspects, including game usability, game mobility, gameplay components, and the efficacy of the learning content.

III. Result and Discussion

A. The Least-Learned Learning Competencies in Grade 7 Living Things and Their Environment (LTE)

The least-learned learning competencies were determined using percentage and rank. Based on the results, the top 5 least-learned learning competencies were (1) focusing specimens using the compound microscope, (2) differentiating plant and animal cells according to the presence or absence of certain organelle, (3) predicting the effect of changes in one population on other populations in the ecosystem, and (4) predicting the effect of changes in abiotic factors on the ecosystem, and (5) differentiating sexual from asexual reproduction in terms of the number of individuals involved and similarities of offsprings to parents.

Table 2 shows the ranking of the learning competencies in Grade 7 Living Things and Their Environment. These learning competencies are ranked from lowest to highest based on the percentage of the participants who answered the test items correctly under a specific learning competency. The results showed that learners have a good grasp of the concepts and competencies about cell as the basic unit of life, fertilization, and beneficial and harmful microorganisms.

Table 2. The least-learned learning competencies in Grade 7 living things and their environment

Learning Competencies	Percentage (%)	RANK
Differentiate plant and animal cells according to the presence or absence of organelles	31.7%	1
Focus specimens using the compound microscope	34.25%	2
Predict the effect of changes in one population on other populations in the ecosystem	36.30%	3
Predict the effect of changes in abiotic factors on the ecosystem	38.36%	4
Differentiate sexual from asexual reproduction in terms of: (a) number of individuals involved and (b) similarities of offsprings to parents	41.1%	5
Describe the different ecological relationships found in an ecosystem	42.00%	6
Describe the different levels of biological organization from cell to biosphere	47.48%	7
Differentiate biotic from abiotic components of an ecosystem	48.98%	8
Identify parts of the microscope and their functions	50.34%	9
Identify beneficial and harmful microorganisms	51.51%	10
Describe the process of fertilization	52.74%	11
Explain why the cell is considered the basic structural and functional unit of all organisms	54.79%	12

With regards to the identified least-learned competencies in Grade 7 Living Things and Their Environment, the findings align, corroborate, and are consistent with the results of previous research studies.

Related literatures do not explicitly state or address that differentiating plant and animal cells as a difficult topic to learn or is least-learned. However, several studies did mention cell-related topics that possibly affects learners conceptual understanding and learning the difference between plant and animal cells. One is that of Chu's [43] in Reddy and Mint [44] study which revealed that despite understanding cell concepts, students still lack clear knowledge about cell structures, which are crucial in distinguishing plant and animal cells. Understanding these structures can help students differentiate between sample cells. another important related finding was that students have difficulties seeing cells as three-dimensional structures rather than two-dimensional ones. This misconception can remain from elementary school through college if not clearly addressed [45]. Furthermore, it is interesting to note also that Students often commit to memory the names and locations of organelles without comprehending their functions or accurate positions within the cell. This results in inconsistent representations and a deficiency of coherence in their drawings [46]. Drawings and diagrams are instrumental in the development of understanding on the differences between plant and animal cells.

Focusing specimens under microscope requires learners to use active and hands-on use of a compound microscope. The result specifically in this part of the study was parallel to the findings of several pieces of literature which tackled the problems encountered in facilitating active learning and hands-on activities, particularly in the topic of Microscopy. Students frequently possess inadequate practical experience with microscopy, hindering their comprehension and application of principles such as contrast and resolution. This deficiency in practical expertise may impede their capacity to concentrate specimens properly [47]. Furthermore, class size is also a factor when Gould *et al.* [48] revealed that instructing large classes in microscopy techniques is notoriously challenging and that conventional approaches may lack the personalized attention required for pupils to effectively master focusing strategies. Ruščić *et al.* [49] corroborate this by identifying multiple factors that hinder the use of microscopes in biology education, including: inadequate microscope availability, an overloaded biology curriculum, spatial and storage constraints, absence of specialized classrooms, teacher uncertainty, excessive student numbers, and insufficient microscopic preparations. The study by Abas and Marasigan [50] revealed that schools with insufficient laboratory facilities impeded the execution of activities in the scientific module developed by the Department of Education. These encompassed the absence of a laboratory room, insufficient laboratory facilities and scientific apparatus, and malfunctioning laboratory equipment, among other issues. The aforementioned issues

were intensified by the adoption of distance learning modes during the COVID-19 pandemic. This pertains to the instructors' concerns regarding the instruction of the learning skill related to focusing a specimen under the microscope. The availability of students to school facilities and equipment, as well as the possibility to perform demonstrations and hands-on activities, has been adversely impacted. Students lacked access to microscopes, preventing teachers from instructing them in the proper use and manipulation of the equipment.

The learning competencies, namely predicting the impact of changes in one population on other species within an ecosystem and predicting the effects of changes in abiotic factors on the ecosystem, are delineated by principles in Ecology. Ozkan *et al.* [51] identified ecological principles as among the most important and difficult to master within the biology curriculum. Ecology is an intricate and extensive subject under Biology that encompasses individual species, the physical environment, and the interactions among organisms as well as between organisms and their environment. This indicated that teaching on Ecology entailed the concretization of concepts perceived by learners as inherently abstract. Students must engage either directly with the natural environment to observe firsthand the interactions within the ecosystem or utilize educational tools that replicate a comparable environment to enhance understanding of abstract topics. This necessitated the application of a suitable technique and resources in instructing ecology ideas that would enable pupils to witness real-world phenomena. Engaging with biology ideas in an outdoor setting positively influenced cognitive development [52]. This finding is supported by Baker [53] and Albedyll *et al.* [54] that comprehending ecological topics solely through textbooks is inadequate; experiential and practical actions are essential for enhanced understanding.

Genetics encompasses the learning skill of distinguishing between sexual and asexual reproduction. In a larger sense, Chu's [43] study found that beginning teenage learners' prior understanding of genetics was generally weak, and alternate perspectives and misconceptions were common. In terms of teaching problems, Chavan [55] found that science teachers struggled to explain biology topics such as cell, sporogenesis, segmentation, scurvy, anemia, and asexual reproduction. In the same study, these challenges were linked to the lack of teaching aids, insufficient reference materials, the amount of time spent teaching, and the level of comprehension. Plant reproduction and human reproduction are specific topics in which sexual and asexual reproduction can be taught. Consistent with the current findings, prior research has shown that students encounter difficulties in correlating the stages of plant reproduction, frequently confusing processes such as pollination and seed dispersal. Numerous students explain merely one procedure and neglect to comprehend their sequential arrangement, signifying a must for explicit education to address these misunderstandings [56]. Furthermore, a considerable deficiency exists in the comprehension of human reproductive anatomy and physiology. Many students struggle to accurately identify reproductive organs or comprehend the locations of gamete generation and fertilization, despite the use of visual aids [57].

The results of these studies might explain why students experienced difficulty in learning or mastering concepts related to these learning competencies. Another reason was the insufficiency of learning content that teachers could access from the learner's manual in Grade 7 Science as they were limited. The results cited in this part strongly supported the goal of this study which was to develop a game-based mobile learning application from the least-learned learning competencies of learners and teaching difficulties of teachers.

B. Game-Based Mobile Learning Application in Living Things and Their Environment

This game-based mobile learning application was created to support teaching and learning for Grade 7 Living Things and Their Environment. This mobile learning application sought to meet the needs of learners in a 21st-century classroom setting in a fun, dynamic, and engaging way while also addressing the learners' least-learned learning competencies. The five learning competencies identified through a learner competency test served as the main points for the game content included in the mobile learning application.

1) Learners' preferred game types

Designing and developing the component games was the same as analyzing the games where certain elements must be considered. This part presents the game types that were used as formats of the games included in the mobile application and were identified using rank and percentages. Learners are asked of their top 3 preferred and commonly played game types. Table 3 shows the ranking of these game types from highest to lowest, meaning, from the most preferred to least preferred. It showed that learners prefer and frequently play adventure, puzzle, role-playing, simulation and strategy types of mobile games.

Table 3. The preferred game types or formats of learners

Game Types	N	%	RANK
Adventure	32	18.0	1
Puzzle	31	17.4	2
Role Playing	29	16.3	3
Simulation	28	15.7	4
Strategy	23	12.9	5
Action	15	8.4	6
Fighting	11	6.2	7
Sports	9	5.1	8
TOTAL	178	100	

The results are consistent with the results of existing studies. In a review conducted by Jabar and Felicia [58], they showed the most popular game is the Role-Playing Games (RPGs) followed by puzzle, action-adventure, competition, simulation, problem-solving, and strategy games. Similarly, in the study of Hainey *et al.* [59], strategy games emerged to be the most played followed by puzzle, simulation, role-playing, adventure, and generic games. It shows that the top 5 game types that emerged to be the most preferred are within those that were also mentioned in previous studies. Ultimately, in the systematic review conducted by Umamah [60], existing studies revealed that the most played game types are strategy, puzzle, role-playing, action-adventure, and simulation.

2) Basic features of the game-based mobile learning application

The game-based mobile learning application included two basic features: an app information page and a menu list with 4 games with game rules for each. The app information page explained what the application was about, what learning competencies were included, how the games were designed, and what each game was about. The games included were MicroSim, PuzzCells, ReproDefenders, and PredicTerms. Each of the 4 games represented the learning competencies that were shown to be the least learnt by learners. The games featured a variety of game categories, including simulation, puzzle, adventure, and word games. The ReproDefenders and PredicTerms were both quiz-like games. Each game contained a different game instruction for players on how to traverse the game. Each game had its own point or scoring system, which served as a motivator and sense of accomplishment for students. Each game provided learners and players with rapid feedback, whether they were still working on the task or objective of the game or had completed it.

A game's icon represented the mobile application's identity. According to Hou and Ho [61], the icon sometimes largely determined the first impression thus, if the impression formed of the icon did not match the gameplay component or its function, it might create opposition to the game's entry and acceptability to the user. The logo of the mobile application material—iLTE: iLearn, iThink, iExplore is shown in Fig. 2. The researcher developed the concept for the logo, which was then materialized by the graphic designer. The lowercase "i" in the name of the mobile learning application signifies the perspective of the learner or user. The letters L, T, and E represented the abbreviation for Living Things and their Environment. Nonetheless, it also possessed alternative meanings such as "Learn", "Think", and "Explore". These terms accurately delineated the actions anticipated of users with the application. The mobile application enables users to learn LTE ideas, think in addressing game challenges and questions, and ultimately explore the subjects of Living Things and Their Environment in an enjoyable and engaging manner.

Fig. 2. Icon of iLTE.

a) Contents of "iLTE"

The mobile application material created contained specialized topics for Grade 7 Living Things and Their Environment, including Plant and Animal Cells, Microscopy, Reproduction, and Interactions. The learning competencies associated with these topics were recognized as the least-learned by learners. These served as the foundation for creating the games featured in the mobile learning app. The learning competencies included: (1) differentiating plant and animal cells according to the presence or absence of certain organelles, (2) focusing specimens using the compound microscope, (3) predicting the effect of changes in one population on other populations in the ecosystem, and (4) predicting the effect of changes in abiotic factors on the ecosystem, (5) differentiating asexual from sexual reproduction in terms of: (a) number of individuals involved.

The navigational structure of the game-based mobile learning application was connected to the main page as shown in Fig. 3. On the main page was where you could also find the menu list of the games included in the application represented by their respective game icons. Also included in the Menu Page, as shown in Fig. 4 was the Game General Information providing users the information about the game and the application as a whole. This could be accessed by clicking the question mark icon on the lower right side of the screen.

Fig. 3. Main page and menu list of games in the application.

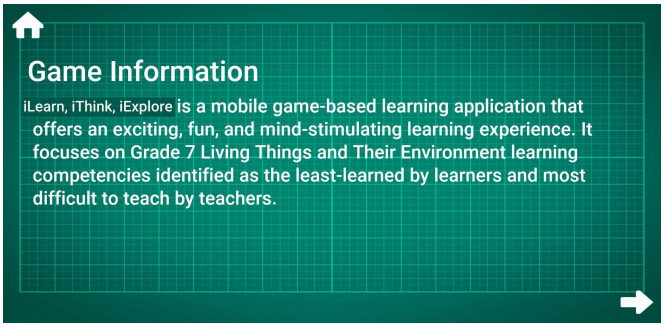

Fig. 4. General game information page.

As shown in Fig. 3, each game had its corresponding icon that gave them their identity and could provide the users with their first impression of the games. The researcher used his experience and aesthetic skills in creating the icons which were materialized by the graphic designer. According to Taquet *et al.* [62], designers could draw from their subjective experience and use their aesthetic skills to create icons based on the users' needs. Each of these icons also tend to convey ideas and emotions to users which could attract their attention. So, if the purpose of an icon was also to convey ideas and emotion to users, then it is aligned with the idea of Shen *et al.* [63] when they posited that the creation of an

appropriate and successful icon could make the user's operation process easy and smooth by eliminating communication barrier between the computer and the user.

Fig. 5(a) shows the icon of the stimulation game MicroSim represented by a simple clipart of a microscope, which could be easily understood that its icon represented its learning content; Fig. 5(b) represents the icon of PuzzCell, which shows an aggregate of four square-like shapes forming a drawing of an organelle. Fig. 5(c) represents the icon of the third game which is the ReproDefender. A deoxyribonucleic acid (DNA) strand could be seen displaying the learning content on sexual and asexual reproduction and the punching gloves exhibited the game type. Lastly, Fig. 5(d) depicts the icon of PredicTerms with different cliparts like brain, image, magnifying lens, and question mark and exclamation point which supported its game type of predicting or completing a term with textual and pictorial hints.

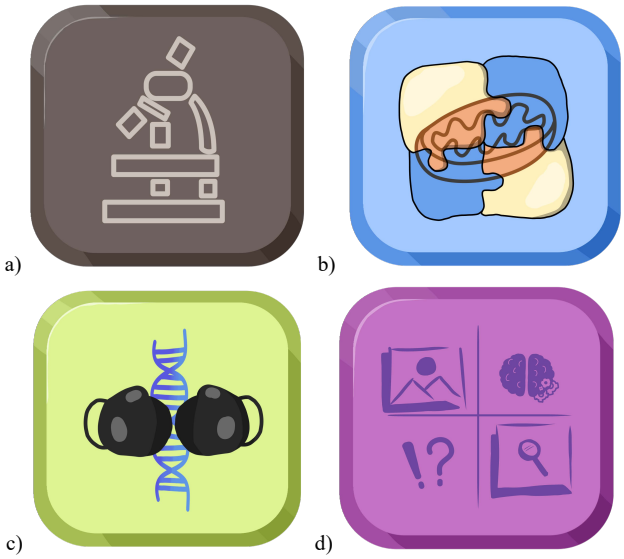

Fig. 5. Icons of the mobile games in iLTE: (a) MicroSim, (b) PuzzCell, (c) ReproDefenders, and (d) PredicTerms.

Individually, each game was of a different game type and included the learning content for each learning competency. MicroSim, which stands for Microscope Simulation, was designed to help players recognize microscope parts and follow the proper sequence of procedures when focusing a specimen under the microscope. A virtual lab assistant named Franz would be available to advise the gamer on what to do. To move further in the game, one must complete the tasks assigned by the lab assistant. This mechanic draws on scaffolding, as the assistant provides ste-by-step guidance to support learners in mastering procedural skills, gradually fostering independence in a constructivist manner. PuzzCell (a combination of puzzle and cell) was a basic puzzle game that allowed players to complete a plant and animal cell by dragging and dropping the various cell organelles into their respective locations within the cell. Plant and animal cells were played individually, although using the same collection of cell organelles. Thus, the player must understand which organelles belong to plant and animal cells. Furthermore, cell organelles were described so that students could learn and get familiar with them. The drag-and-drop interaction promotes constructivism by enabling active knowledge construction through trial and error, while the integration of visual puzzles with textual descriptions aligns with dual coding theory to reinforce conceptual understanding via multiple cognitive channels. The third game, ReproDefenders, was an adventure game with two main characters: sexual and asexual. The player must aid these characters defeat the monsters. Each character has unique abilities that enabled them to combat various creatures. To defeat the creatures, one must carefully analyze their descriptions in order to identify which character and which exact weapon should be employed. This problem-solving approach embodies constructivism, as players actively apply and refine their understanding of concepts on sexual and asexual reproduction through experiential learning in a simulated environment. Finally, PredicTerms is a word game in which players could predict or guess the term using text and images as prompts. Some letters from the word that players would guess were provided as well to help them determine the right term. The terms were relevant to the aforementioned learning competencies (3) and (4). The use of multimodal prompts, which include texts and images, leverages dual coding theory to enhance memory and comprehension of terms related to Ecosystem and Ecology, with partial letter hints offering scaffolding to guide learners toward correct responses without overwhelming cognitive load.

As you individually click and further explore each game, you would be directed to their respective start-up page. Here, you could find the title of the game and a short description of what the game was all about, and a little overview of what to experience, just like what is shown in Fig. 6, a sample game start-up page of ReproDefenders with game information.

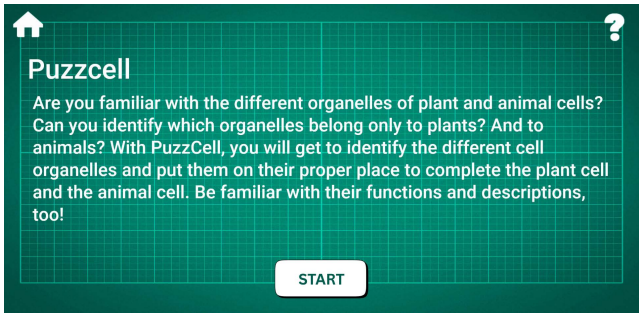

Fig. 6. A sample start-up page of a game (ReproDefenders).

Aside from a short description of the game with its title, the Start-up page also included a HOME icon in the upper left corner and a QUESTION MARK icon in the upper right corner of the page. Clicking this icon would direct users to Game Instruction Page. This page would provide detailed instructions or mechanics on what the learners will do and how to play the selected game. Fig. 7 shows a sample Game Instruction Page of ReproDefenders.

When users finally become ready to engage and explore the games, they will just have to click the "START" button and they would be directed to the page where the game was set up. Fig. 8 shows the game set-up of the simulation MicroSim. A lab assistant would welcome and guide you as go along the process of learning the parts and functions of and how to properly use the microscope in focusing a specimen. You might also find "BACK" and "NEXT" buttons on the screen to help you navigate the simulation. Fig 9 shows a portion of the game-simulation where users are presented with the different objective lens of a microscope and are asked to drag the names into their corresponding parts.

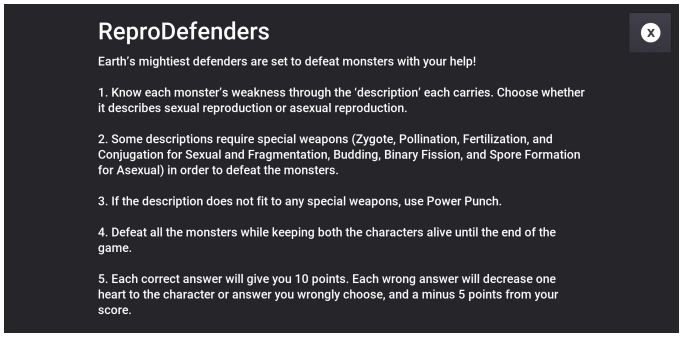

Fig. 7. Sample game instruction page of a game (ReproDefenders).

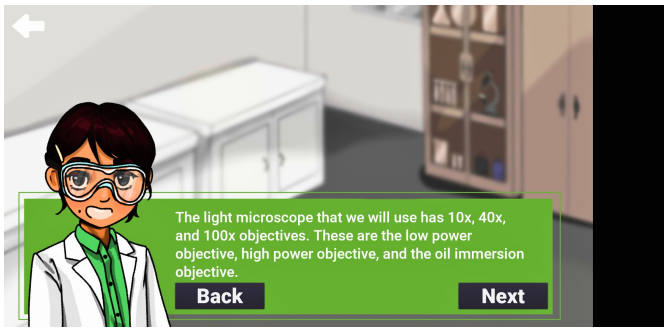

Fig. 8. Sample screenshot of the frame or user interface of MicroSim.

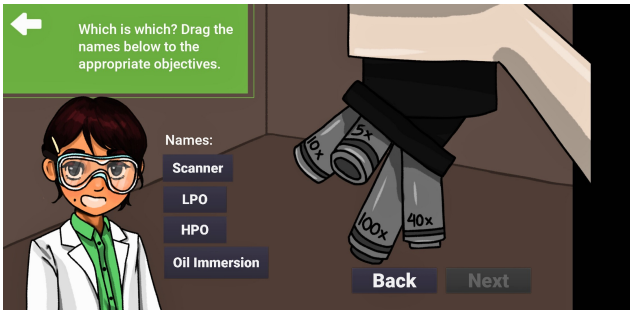

Fig. 9. Screenshot of a sample portion of the game-simulation, MicroSim.

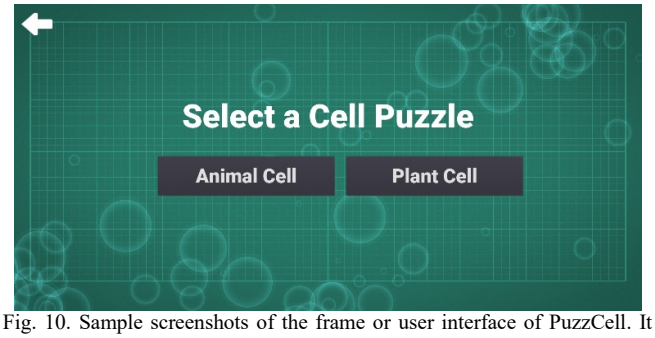

Fig. 10. Sample screenshots of the frame or user interface of PuzzCell. It shows the interface where players get to select which puzzle to play, Animal Cell and Plant Cell.

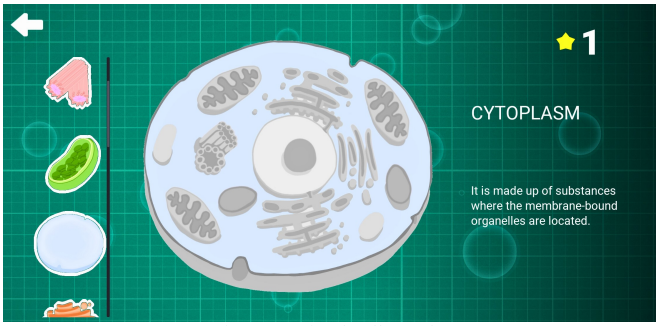

Fig. 11. Animal cell puzzle.

In PuzzCell, as shown in Fig. 10, when you click its game icon in the Game Menu page, it will direct you to a page where you get to select which puzzle to play: Animal Cell as shown in Fig 11, or Plant Cell as shown in Fig. 12. Play. Players are tasked to drag and drop the organelle to its respective location in the cell. The set-up of the game was composed of a column of cell organelles on the left side of the screen and a blank cell template at the center.

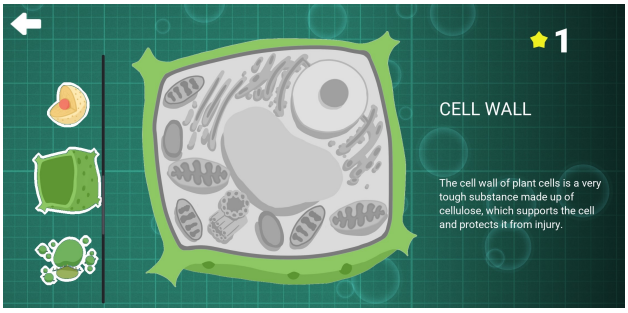

Fig. 12. Plant cell puzzle.

In the third game, ReproDefenders, two in-game characters, Sexual and Asexual are present in the game which could be controlled by the player in defeating the monsters at the center of the screen. Players must choose among the weapons on the left side of the screen which must be used by the appropriate character as shown in Fig. 13. The weapons in the left side are represented by the different conceptual terms related to sexual and asexual reproduction such as zygote, pollination, conjugation, fragmentation, budding, spore formation and the likes. The appropriate weapon to be used to defeat the monster depends on the description or definition that appears beside it as shown in Fig. 14.

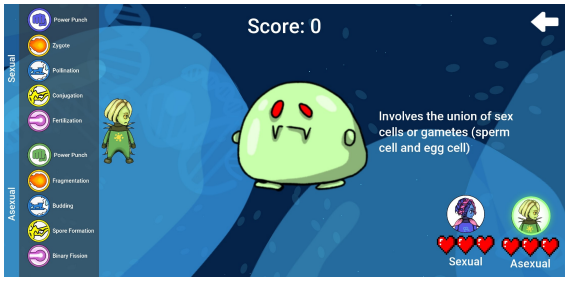

Fig. 13. Sample screenshot of ReproDefenders showing the placement of characters and icons in the game

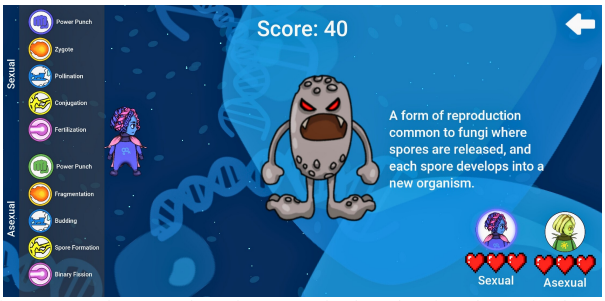

Fig. 14. Sample screenshot of ReproDefenders showing change in character, concepts, and points within the game

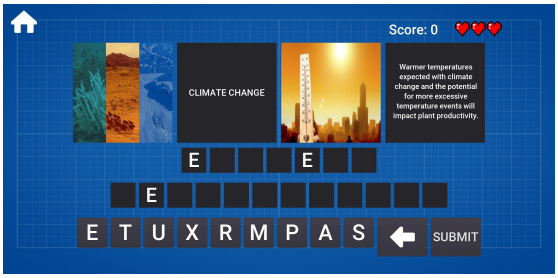

Fig. 15. Sample screenshot of the frame or user interface of PredicTerms. The term being described is extreme temperature.

Lastly, Fig. 15 shows the game set-up of PredicTerms where, unlike other word puzzles in mobile games, it did not solely rely on pictures used as hints. LTE concepts in the form of text were also used in addition to pictures.

3) Implementation of the game-based mobile learning application

The game-based mobile learning application was utilized as teaching material in a Grade 7 regular class at a public high school in the researcher's hometown. Essential preparations were conducted prior to the implementation. The researcher convened with the learners multiple times during the preparatory phase. Participants received letters of informed parental consent, which the researcher ensured were duly signed by their parents. A copy of the Android Package Kit for the mobile learning application was dispatched to learners' Android phones and was successfully installed. The researcher developed contextualized lesson plans to address the learning competencies. One week before to the implementation, the teacher-implementer, a Grade 7 Science teacher and a trainer in workshops and seminars, collaborated closely with the researcher. Guidance and recommendations for the effective implementation of the instructional material, utilizing the lesson plan, were provided to the teacher-implementer. The teacher-implementer's willingness and openness to participate in the study significantly enhanced the implementation process. As only the PuzzCell game was implemented, the execution occurred in a single session. Adhering to the lesson plan, the session followed the 7 Es framework (Elicit, Engage, Explore, Explain, Elaborate, Evaluate, and Extend). During the Elicit phase, MicroSim, a simulation demonstrating how to focus a specimen under a microscope, was utilized, as it was the preceding topic relevant to the learning competency to be addressed.

With the identified least-learned learning competencies of the learners, plus the identification of key game types and formats, a game-based mobile learning application was conceived. This mobile learning application will effectively address these educational deficiencies in an interesting and exploratory manner through game-based and mobile learning techniques. This educational resource would be beneficial for learners, as it would allow them to access and participate in learning activities through games, enabling them to learn at their own pace without the limitations of attending school during distance learning or as an after-class extension activity. Moreover, this designed educational material promotes learners' active engagement in the learning process and transforms teachers' roles into that of facilitators. Consequently, the implementation of this game-based mobile learning application is strongly advocated for both educators and students as a contemporary and inventive approach appropriate for a 21st-century classroom.

C. The Evaluation of the Acceptability of the Game-Based Mobile Learning Application in Grade 7 Living Things and Their Environment

After the implementation of the game-based mobile learning application, phase III took place with the evaluation of the mobile application by teachers and learners in terms of its acceptability for classroom use. Guide questions were also employed to unravel the experiences of teachers and learners in using the mobile application. 'What can you say about the mobile application's components? Did you find the mobile learning application useful? Did the mobile learning application help you in learning Living Things and Their Environment?' were some of the leading questions that were asked.

This part unfolds the acceptability of the game-based mobile learning application in terms game usability (GU), game mobility (GM), gameplay (GP), and learning content (LC). The mean and standard deviation were utilized to solve for the evaluators' perception of the degree of acceptability of the developed game-based material. Table 4 shows the evaluators' evaluation of the acceptability of the game-based mobile learning application.

Table 4. Acceptability of the game-based mobile learning application based on four dimensions

Dimensions	SD	M	Description
Game Usability	0.32	3.83	Very Acceptable
Game Mobility	0.60	3.62	Very Acceptable
Game Play Component	0.36	3.85	Very Acceptable
Learning Content	0.61	3.88	Very Acceptable
Overall Rating	0.47	3.79	Very Acceptable

Note: n = 6: Interpretation is based on the following scale/ criteria: 1.00–1.50 = Barely Acceptable, 1.51–2.50 = Moderately Acceptable, 2.51–3.50 = Acceptable, 3.51–4.00 = Very Acceptable

The overall acceptability of the game-based mobile learning application was rated as very acceptable (M = 3.79, SD = 0.472). Specifically, game usability was highly rated with very acceptable (M = 3.83, SD = 0.32), indicating that the application's interface and navigation were intuitive and user-friendly. Gameplay was similarly well-received (M = 3.85, SD = 0.36), suggesting engaging and effective game mechanics. Learning content received the highest rating (M = 3.88, SD = 0.61), reflecting strong alignment with the Grade 7 "Living Things and Their Environment" curriculum and clarity of educational material. Game mobility, while still rated as very acceptable (M = 3.62, SD = 0.60), had the lowest mean score among the dimensions, possibly due to minor technical constraints, such as device compatibility or responsiveness on varied screen sizes.

These results imply that the application functions effectively as a supplementary instructional tool, with all dimensions meeting high acceptability standards. The strong scores in usability, gameplay, and learning content suggest that the application is well-designed for educational purposes, engaging learners while delivering curriculum-aligned content. However, the slightly lower game mobility score indicates potential areas for improvement, such as optimizing performance across a wider range of mobile devices or enhancing offline functionality to support diverse learning environments. These findings support the application's suitability for blended learning contexts but suggest that future iterations could prioritize addressing mobility-related technical enhancements to further improve accessibility and user experience.

As a game-based learning material, the findings above are consistent with that of Marengo *et al.* [64] that Game-Based Learning (GBL) environments integrate game technology with pedagogical methodologies to deliver captivating educational experiences. This shows the importance of relevant content integration in game-based learning environment. Furthermore, findings also agree with

Zaibon [65] in terms of game usability and playability, that mobile game-based learning applications must evaluate game usability, mobility, playability, and educational content to verify that the material fulfill user requirements and he mentioned that high acceptability rating in these dimensions indicate that the developed material is easy to use with a well-designed interface, user-friendly by providing a seamless experience with less to no technical issues, engaging, effectively retains players' interest and motivation, and effectively delivers the intended learning content making it educationally valuable.

Descriptive numerical findings on the acceptability of learning material are consistent with the positive and perceptive comments from evaluators and validators. These include (a) "Contemporary learners appreciate education when it incorporates audio-visual elements. I believe this educational content will enhance learner engagement in the learning process"; (b) "The mobile learning application, designed for gaming, was engaging, exploratory, and highly enlightening. Learners not only acquire knowledge from it but also experience enjoyment and excitement while utilizing it. The game is enjoyable and captivating, prompting learners to actively engage in class discussions"; (c) "The first look of the menu and game title captivated my interest. The game was ingenious, as it converted science-related themes into battles or minigames, each requiring me to attempt again"; (d) "Overall, it is an impressive game that I believe could be advantageous for both students and teachers in the long term".

These positive insights are in accord with recent studies indicating that the use of games infused in mobile devices in an educational setting helped raise students' motivation and consequently advanced the attainment of learning outcomes as supported also in a related study by Mivehchi and Rajabion [66]. The motivating aspect of game-based learning highlights games' capacity to engage and motivate players by offering enjoyable experiences that encourage further participation [67]. This acknowledged the potential of mobile game-based learning to integrate game-based learning with mobile learning. Moreover, the study revealed that integrating gaming into the educational process rendered it pleasant, comprehensible, and accessible to learners, serving as a significant source of motivation and engagement due to its inherent entertainment value. The findings of this study also aligned with that of Davis [68] in Krouska *et al.* [69] where he mentioned that in the Technology Acceptance Model, the perceived ease of use was a factor that greatly affected the acceptance of a new system taking into regard the users' intention to use and their attitude towards its utilization. This showed that with regards to the game-based mobile learning application, the target users of the learning application should perceive it as easy to use and easy to navigate to compensate and subdue the limitation of mobile devices which usually have small screen thus also limiting users' screen interaction.

D. Learners' Perception and Experiences in the Use of the Game-Based Learning Material

Perceptions and experiences of learners were also captured and noted in using the game-based mobile learning application during the implementation phase. Learners were still able to use the learning material beyond the implementation session, whether they were in school or their homes. Illustrations, ease in learning LTE concepts, ease of game instructions, and learning content were given consideration and these are the summarized perceptions of learners, respectively:

1) Visually Appealing and Engaging Design. The illustrations are accurate, well-designed, and visually appealing. The audio-visual representation supports the game, and the screen layout is efficient and visually pleasing. These perceptions supported the "very acceptable" rating for the game usability component, particularly for audio-visual representation and efficient, visually pleasing screen layout. Overall, the illustrations are visually appealing and informative. One learner, however suggested the graphic design needs improvement.
2) User-Friendly and Easy to Learn. The application and game instructions are user-friendly, providing clear, step-by-step guidance for easy comprehension and enjoyment, making them advantageous for learning and enjoyment in mobile games. Learners described the app as "very easy", "easy to understand", and noted that game instructions were clear, easy to follow, well-explained step-by-step, and useful. These perceptions align with the "very acceptable" ratings for game usability (useful help) and learning content (easily learned and understandable content).
3) Useful and Relevant Learning Content. The mobile application is really beneficial and may be used to learn a variety of scientific concepts. Learners generally described the embedded learning content as very useful, explicitly stating that it followed their current Science lessons (Grade 7 LTE). They found it helpful in learning many things in Science, was easy to learn and understand, and enabled them to learn specific topics like microscopy, plant and animal cells. The learning content component received a "very acceptable" rating, indicating that the content is easily learned, understandable, and has achievable learning goal.
4) Positive Impact on Learning. Learners found the mobile learning application useful for learning LTE concepts and acquiring additional knowledge through fun and interactive characters which helped them understand the content. The game-based mobile learning application's usefulness was attributed to its ability to deliver intended learning content and outcomes to learners, highlighting its importance in enhancing their knowledge.

The study also revealed learners' experiences on the use of the game-based mobile learning application.

1) Novelty and Encouragement. Some learners were new to using the material in their Science class, but found it encouraging and easy to learn. They also appreciated the clear goals and clear learning content which highlights the novelty of using a game-based application in learning instruction.
2) Enjoyable and Fun Learning Environment. Learners also found that the fusion of mobile learning applications with games and learning content was enjoyable to use through playing games, answering questions, and learning new topics. They described it as "so fun", "amazing", and

noted that it lightened their mood and made learning enjoyable, fulfilling both leisure and educational purposes.

3) Effective Content Acquisition and Active Learning. Science content including topics like microscopy, plant and animal cells, sexual and asexual reproduction, and biotic and abiotic factors were integrated learned in a mobile learning application and were learned through interactive games. They learned about specific concepts like where cells are found, bacterial reproduction, and the parts and uses of microscope through interactive elements like the MicroSim. The game-based mobile learning environment, with its clear and easy-to-follow game rules and mechanics, was found to facilitate the development of cognitive skills, including neural processing, spatial skills, problem-solving, and creativity. The application provided an environment for learners to actively build their own knowledge and meaning, supporting active learning and increasing motivation.
4) Effortless Navigation and Engagement. Learners experience ease in maneuvering and learning to use the mobile application, which helped them discover things. This experience corroborated their perception of ease of use. The challenging nature of the games was also noted as a factor in increase engagement, which is a strong predictor of learning outcomes.

Overall, the mobile learning application was a valuable tool for students, praising the mobile application's ease of use, quality of graphic designs and meaningful and understandable science concepts. However, the study reveals that some learners find learning about cells challenging and require strategies while other learners think that prolonged engagement with the game-based material induces boredom due to its repetitive nature, even after multiple completions of the game. The data revealed different perspectives on the game-based mobile learning application, focusing on graphic design quality, ease of use, relevance of content, satisfaction, and suggestions for improvement.

Some researchers had already justified how mobile game-based learning engaged learners not only to play for leisure pursuits but also for educational purposes and learning [70]. Learners' engagement in the games in a game-based learning environment was also proven to show a clear positive effect on learning, as revealed in another study by Hamari *et al.* [71]. This increased engagement was attributed to the challenges encountered by learners in the game. As they have described, particularly by the teachers in their experiences, the developed game-based mobile learning application was characterized as challenging. Furthermore, as they supported, the challenge in the game was a strong predictor of learning outcomes. Thus, it was suggested in the same study to have the challenge of the game be able to be on the same page with learners' developing abilities in order to sustain learning in game-based learning environments. In addition to the learners' engagement, intrinsic motivation was also supported by the different game elements found in the game-based mobile learning application namely, game rules and mechanics, narrative elements, and game aesthetics. Part of the game rules and mechanics was the game instructions which direct learners in using and guiding them in playing the games. Based on the result of this study, learners described the game instructions of iLTE as easy to follow and understand. Having good and effective game rules and mechanics, as Granic [72] revealed, facilitated the development of cognitive skills which include neural processing and efficiency, spatial skills, enhanced mental rotation abilities, problem-solving skills, and creativity. Since this study dealt with digital games, that was in the form of a mobile game, and game-based learning, both of which had been traditionally linked to the constructivist perspective of learning [73], learners' cognitive and emotional experiences in using the game-based mobile learning application provided them with an environment where they could build their knowledge and meaning aligned with specific learning outcomes. Thus, generally, this emerging and exciting pedagogical and educational strategy i.e. game-based mobile learning, supported learners' active learning and consequently might improve academic performance and increase the level of motivation.

The successful development and assessment of the game-based mobile learning application in this study have broader implications for the educational landscape, beyond the specific setting of Grade 7 LTE (Biology). The results strongly support a shift in teaching methods, highlighting the need to incorporate technology to develop more dynamic, engaging, and successful educational settings. This corresponds with the claim by Sagge and Segura [74] that educators must transition from traditional pedagogical methods to engage and instruct current generations of learners, who frequently find conventional approaches unengaging. The study's findings indicate that mobile learning technologies, including the developed games, can effectively make complex and abstract concepts more tangible and accessible [75], a principle applicable across diverse disciplines and educational levels. Moreover, the ramifications of this research pertain to the cultivation of 21st-century competencies. Bacio [76] posits that innovative educational methodologies enhance both the acquisition of subject-specific competences and the development of vital skills for lifetime learning and future employment requirements. The elevated evaluations for game usability, mobility, and gameplay highlight the capacity of well-developed educational games to cultivate critical thinking, problem-solving, and digital literacy skills. The transformative potential of digital learning technologies, as emphasized by Bacio and Sagge [77], resides in their capacity to enhance student involvement and understanding, equipping students for successful professions. This further underscores the notion of adaptable and stimulating learning alternatives for attaining specified educational objectives, as evidenced by the efficacy of student-generated podcasts [78]. The notable efficacy of the MicroSim game in imparting a practical skill substantiates the assertion by Torion and Bacio [79] on the utilization of interactive and visual mediums for practical skill learning. This study urges educators, curriculum authors, and politicians to advocate for the incorporation of evidence-based, purpose-designed educational technologies to foster a more fair, engaging, and forward-looking educational environment.

While this developmental study demonstrates the potential of a game-based mobile learning application to address least-learned competencies in Grade 7 LTE, several

limitations are noted to contextualize the findings. First, the participant selection was purposive, involving learners from a public secondary school which may limit the generalizability of the results to broader populations or diverse educational settings. The sample size for the Learners' Game Format Preference questionnaire (n = 73 Grade 8 learners) was relatively focused on a specific grade level, potentially restricting insights into preferences across different age groups or grade levels. Additionally, the evaluation emphasized acceptability through reported measures through the evaluation form, but did not include objective assessment of learning outcomes through pre- and post-intervention tests on the identified learning competencies. Future research could incorporate such designs, such as quasi-experimental studies, to empirically evaluate the effectiveness of the game-based mobile learning application in improving mastery of Grade 7 LTE competencies. Expansions to other science units or grade levels could test the scalability of the ASSURE model in game-based learning. Additionally, investigating accessibility adaptations for low-resource environments would further enhance the practical applicability of such applications in public education systems.

Additional limitations include potential constraints related to device compatibility, access to mobile phones, and long-term engagement. The mobile application is compatible only to smartphones and not to iOS and tablets due to software and screen size restrictions, potentially affecting performance in diverse technological contexts. Furthermore, access to mobile devices, particularly in low-resource public schools, may pose barriers to equitable implementations, as not all students may have consistent access to compatible smartphones. Also, sustained engagement was not assessed due to the study's short-term evaluation which occurred for two weeks.

IV. Conclusion

This study demonstrated the potential of mobile games to be integrated into Grade 7 LTE, specifically in addressing least-learned competencies. The novelty of this study resides in its nature of targeting identified learning competencies. Unlike previous works that focus on general concepts in science, this study embedded empirically identified least-learned competencies into curriculum-aligned mobile games, guided by the ASSURE instructional design model. Linking instructional design with mobile game-based material development provides a unique innovation in science education, which could provide a replicable model for future researchers and educators aiming to create digital learning materials that directly respond to persistent learner difficulties.

The findings about the least-learned competencies in Grade 7 Living Things and Their Environment revealed that despite the completion of the Science subject, there are still learning competencies that are not fully met and acquired. Thus, teachers should provide additional learning contents and utilize supplementary materials to help learners achieved intended learning outcomes. They may also consider employing hands-on learning activities and design varied motivating and engaging learning activities to decrease the possible difficulty of the subject matter even suited for distance learning modalities.

The finding on evaluators' assessment showed their very acceptable rating and positive feedback on the different dimensions of the game-based mobile learning application suggested that they support the use of digital tools and game-based learning as an adaptation to the changing landscape of teaching and learning in the 21st century, making it an acceptable instructional and supplementary learning material highly recommended to be used by teachers and learners. Generally, the developed learning material was very useful in the teaching and learning process, considering that from a technological view, learners preferred to use mobile phones among other digital tools and had been fond of mobile games. From an educational perspective, the fusion of games in the educational process enhanced learners' motivation and engagement for learning, that may lead to the achievement of desired learning outcomes.

Learners' high regard for the game-based mobile learning application suggested that game-based learning, indeed, allowed learners to experience learning firsthand in a fun and enjoyable way. Also being technology savvy, they were very receptive to the idea of fusing games and learning content in a digital tool, particularly the use of mobile phones. They also recognized the flexibility of using a game-based mobile learning application, that was, either within the four walls of their classroom during formal instructions or outside the school setting, anytime and anywhere. Furthermore, their positive feedback on the graphic designs, game mechanics, ease of use, and learning content suggested the suitability of the developed material to them as target users.

The development and use of this learning material highlight the incorporation of game designs and ICT tool in the pedagogical process through a game-based mobile learning application which offered authentic learning tasks and strongly supported the learner-centered curriculum. Learners also take an active part in learning process and their previous knowledge and experiences should be seen as a reference point to introduce and generate new knowledge, guided by the teachers as facilitators of learning. This study has contributed to the existing knowledge on the use of game-based learning and mobile learning which might provide helpful insights in the field of research, instruction, and possibly extension work. Though game-based learning has been used extensively in teaching and learning, the development of tailored-fit game-based materials from learners' needs seem to provide a filler in the gap of using game-based materials in instruction. On a practical sense, this learning material may be utilized for blended learning modality where learners can access the topics and learning contents in LTE through a game-based mobile learning platform in a self-paced, enjoyable and motivating manner.

Utilization of such may pave way in improving ICT use guidelines in schools such that mobile phones through educational software application like mobile games can be used in addition to common ICT tools in the lesson suitable for learners and the learning context. In addition, instructional material developers may consider using game-based mobile learning applications as additional material to be included in the learning activities presented in the modules or textbooks or include in modules learning and teaching guides in using a specific learning application in a face-to-face or blended learning instruction. It may also be

suggested that teachers may choose to adapt the process of developing a game-based learning material may it be digital or non-digital. However, they must keep in mind that during the process, the identification of appropriate learning content and necessary learning competencies should be met so that the validity of the material will not be compromised. The study's focus on a particular domain which is the Living Things and Their Environment constrains insights into its broader applicability; however, this still allows for a specific competencies' development. Further exploration may open opportunity for other learning competencies from other domains of Science such as Force, Motion, and Energy (Physics), Matter (Chemistry), and Earth and Space (Earth Science), and across grade levels adapting the ASSURE model and utilizing game-based mobile learning application. In terms of research, experimental studies may be considered to test the effectiveness of the learning material in improving least-learned competencies.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Paris contributed in conceptualizing, offering guidance and suggestions for enhancing the study, reviewing the manuscript, and proofreading the article; Solomon helped in conceptualizing, designing, and carrying out the research study, designing the mobile application, and polishing the manuscript. All authors approved the final version.

ACKNOWLEDGEMENT

The authors would like to extend their gratitude to the Department of Science and Technology - Science Education Institute (Under the Capacity Building Program in Science and Mathematics Education) and the West Visayas State University-University Research Development Center for their generous support in the completion and publication of this paper.

REFERENCES

[1] A. Bonifacio. (2013). Developing Information Communication Technology (ICT) curriculum standards for K–12 schools in the Philippines. Univ. Philippines, College of Education—Curriculum Studies. [Online]. Available: https://linc.mit.edu/linc2013/proceedings/Session7/Session7Bonifacio.pdf

[2] E. S. C. Ho, "ICT familiarity of East Asian students and effect of ICT factors on students' CBA performance," *What We Learned from PISA: The Outstanding Performance of Students in Hong Kong and East Asia*, pp. 333–362, 2017. doi: 10.1142/9789813146709_0010

[3] S. Yadav, "Integrating ICT in language teaching and learning: Preparing technology-enabled language teachers in the digitally transformed education world," *Handbook of Research on Language Teacher Identity*, pp. 294–309, 2023. doi: 10.4018/978-1-6684-7275-0.ch0016

[4] S. Gillern and Z. Alaswad, "Games and game-based learning in instructional design," *Int. J. Technol. Learn.*, vol. 23, no. 4, pp. 1–7, 2016. doi: 10.18848/2327-0144/CGP/v23i04/1-7

[5] N. Whitton, *Digital Games and Learning: Research and Theory*, New York, NY, USA: Routledge, 2014. doi: 10.4324/9780203095935

[6] R. Misra, L. Eyombo, and F. T. Phillips, "Benefits and challenges of using educational games," *Res. Anthol. Dev. Gamification Game-Based Learn.*, vol. 4, pp. 1560–1570, 2021. doi: 10.4018/978-1-6684-3710-0.ch075

[7] M. Nadeem, M. Oroszlanyova, and W. Farag, "Effect of digital game-based learning on student engagement and motivation," *Computers*, vol. 12, no. 9, 177, 2023. doi: 10.3390/computers12090177

[8] H.-Y. Liang, T.-Y. Hsu, G.-J. Hwang, S.-C. Chang, and H.-C. Chu, "A mandatory contribution-based collaborative gaming approach to enhancing students' collaborative learning outcomes in science museums," *Interactive Learning Environments*, vol. 31, no. 5, pp. 2692–2706, 2023. doi: 10.1080/10494820.2021.1897845

[9] W. S. Yue and T. W. Jing, "Survey analysis: The effectiveness of Game-Based Learning (GBL) in tertiary education environment," in *Proc. 5th Int. Conf. IT Convergence and Security (ICITCS)*, 7293022, 2015.

[10] T. Saba, "Intelligent game-based learning: An effective learning model approach," *Int. J. Comput. Appl. Technol.*, vol. 64, no. 2, pp. 208–221, 2020. doi: 10.1504/IJCAT.2020.111587

[11] N. Vidakis and S. Charitakis, "Designing the learning process: The IOLAOS platform," in *Proc. ACM Int. Conf.*, 2018.

[12] N. Komalawardhana, P. Panjaburee, and N. Srisawasdi, "A mobile game-based learning system with personalised conceptual level and mastery learning approach to promoting students' learning perceptions and achievements," *Int. J. Mobile Learn. Organ.*, vol. 15, no. 1, pp. 29–49, 2021. doi: 10.1504/IJMLO.2021.111596

[13] L. Bennis and S. Benhlima, "Toward a new approach: Extending a game-based learning authoring tool eadventure to multiple mobile devices," *Adv. Intell. Syst. Comput.*, vol. 520, pp. 47–56, 2017. doi: 10.1007/978-3-319-46568-5_5

[14] L. Bennis and S. Amali, "From learning game to adaptive ubiquitous game based learning," *Int. J. Emerg. Technol. Learn.*, vol. 14, no. 16, pp. 55–65, 2019. doi: 10.3991/ijet.v14i16.10701

[15] R. Denham, "Supporting conceptual understanding of the associative and distributive properties through digital gameplay," *J. Comput. Assist. Learn.*, vol. 31, no. 6, pp. 706–721, 2015. doi: 10.1111/jcal.12113

[16] S. Assapun and P. Thummaphan, "Assessing the effectiveness of board game-based learning for enhancing problem-solving competency of lower secondary students," *Int. J. Instr.*, vol. 16, no. 2, pp. 511–532, 2023. doi: 10.29333/iji.2023.16228a

[17] K. Osman and N. A. Bakar, "Teachers and students as game designers: Designing games for classroom integration," *New Pedagogical Approaches in Game Enhanced Learning: Curriculum Integration*, pp. 102–113, 2013. doi: 10.4018/978-1-4666-3950-8.ch006

[18] A. Minelli, "Two-way exchanges between animal and plant biology, with focus on evo-devo," *Front. Ecol. Evol.*, vol. 10, 1057355, 2022. doi: 10.3389/fevo.2022.1057355

[19] C. Byukusenge, F. Nsanganwimana, and A. P. Tarmo, "Difficult topics in the revised biology curriculum for advanced level secondary schools in Rwanda: teachers' perceptions of causes and remedies," *J. Biol. Educ.*, vol. 57, no. 5, pp. 1112–1128, 2023. doi: 10.1080/00219266.2021.2012225

[20] S. Somakeerthi, G. Udani De Silva, L. Thenu De Silva, S. Chandrasiri, and J. Joseph, "Amazon biology: An augmented reality-based e-book for biology," in *Proc. ICAC 2020 2nd Int. Conf. Advancements Computing*, 2020, pp. 1–6, 9357165. doi: 10.1109/ICAC51239.2020.9357165

[21] A. Cimer, "What makes biology learning difficult and effective: students views," *Educ. Res. Rev.*, vol. 7, no. 3, pp. 61–71, 2012. doi: 10.5897/ERR11.205

[22] D. L. Silverio, E. Villa-Cuesta, A. Hyslop, K. Kolack, and S. G. Sobel, "We have more in common than we think: A comparison of scientific skills and disciplinary practices in the guiding documents for biology, chemistry, and mathematics," *Journal of College Science Teaching*, vol. 53, no. 5, pp. 472–479, 2024. doi: 10.1080/0047231X.2024.2373027

[23] P. Hammond, J. Aiton, G. Hughes, and I. Nimmo, "The biology of numbers," *Inspiring Students: Case Studies on Teaching Required Courses*, 2013, pp. 137–148. doi: 10.4324/9781315042169-21

[24] J. R. Honra and S. L. C. Monterola, "Fostering cognitive flexibility of students through design thinking in biology education," *Cogent Education*, vol. 11, no. 1, 2415301, 2024. doi: 10.1080/2331186X.2024.2415301

[25] A. Sapriati, U. Rahayu, I. Sausan, M. Sekarwinahyu, and R. S. Anam, "The impact of inquiry-based learning on students' critical thinking in biology education programs within open and distance learning systems," *Jurnal Pendidikan IPA Indonesia*, vol. 13, no. 3, pp. 367–376, 2024. doi: 10.15294/7sty9026

[26] L. E. Retone and M. S. Prudente, "Effects of technology-integrated brain-friendly teaching on retention and understanding in photosynthesis and cellular respiration," in *Proc. ACM Int. Conf. Series*, 2020, pp. 59–63. doi: 10.1145/3377571.3377590

[27] R. J. D. D. L. Cruz, "Science education in the Philippines," *Lecture Notes in Educational Technology*, 2022, pp. 331–345. doi: 10.1007/978-981-16-6955-2_20

[28] *The Basic Education Learning Continuity Plan in the Time of COVID-19*, Pasig City, Philippines: Department of Education, July 2020.

[29] E. Ambayon, "Modular-based approach and student's achievement in literature," *Int. J. Educ. Lit. Stud.*, vol. 8, no. 3, 2020. doi: 10.7575/aiac.ijels.v.8n.3p.32

[30] A. K. Bednar, D. J. Cunningham, T. M. Duffy, and J. D. Perry, "Theory in practice: How do we link?" in *Instructional Technology: Past, Present, and Future*, G. J. Anglin, Ed., Englewood, CO: Libraries Unlimited, 1995, pp. 100–112.

[31] J. Dewey. (1938). *Experience and Education*. New York: The Macmillan Company. [Online]. Available: https://archive.org/details/experienceeducat00dewe_0

[32] R. Richey and J. Klein, "Developmental research methods: Creating knowledge from instructional design and development practice," *Journal of Computing in Higher Education*, vol. 16, pp. 23–38, 2005. doi: 10.1007/BF02961473

[33] S. Jaya, R. Zaharudin, S. N. A. Hashim, M. A. Ithnin, S. M. Zaid, J. Mapjabil, and M. N. Nordin, "Employing Design and Development Research (DDR) approach in designing Next Generation Learning Spaces (NGLS) in teachers' pedagogy and technology tools," *Rev. Int. Geogr. Educ. Online*, vol. 11, no. 7, pp. 1237–1246, 2021. doi: 10.48047/rigeo.11.07.116

[34] F. Wang and M. J. Hannafin, "Design-based research and technology-enhanced learning environments," *Educ. Technol. Res. Dev.*, vol. 53, no. 4, pp. 5–23, 2005. doi: 10.1007/BF02504682

[35] K. Klaassen and K. Kortland, "Developmental Research," in *Constructivist Learning Design: Key Aspects*, A. Z. Fliessen and K. Kortland, Eds., Cham: Springer International Publishing, 2015, pp. 33–44. doi: 10.1007/978-94-007-2150-0_155

[36] R. Heinich, M. Molenda, J. D. Russell, and S. E. Smaldino, *Instructional Media and Technologies for Learning*, 6th ed., Upper Saddle River, NJ: Merill/Prentice Hall, 1999.

[37] P. Lefebvre, "Infusion of technology in the classroom: Implementing an instructional technology matrix to help teachers," Master's thesis, Dept. of Education, Concordia University, Montreal, Quebec, Canada, 2006.

[38] S. J. P. Bacio and R. J. G. Sagge, "Evaluation of the developed and produced Computer Generated Instructional Materials (CGIM) for college geometry," *International Journal of Multidisciplinary: Applied Business and Education Research*, vol. 3, no. 11, pp. 2329–2342, 2022.

[39] B. Gros, "Digital games in education: The design of games-based learning environments," *J. Study Technol. Educ.*, vol. 40, no. 1, pp. 23–38, 2007. doi: 10.1080/15391523.2007.10782494

[40] T. M. Connolly, E. A. Boyle, E. MacArthur, T. Hainey, and J. M. Boyle, "A systematic literature review of empirical evidence on computer games and serious games," *Comput. Educ.*, vol. 59, no. 2, pp. 661–686, 2012. doi: 10.1016/j.compedu.2012.03.004

[41] S. Šćepanović, T. Vujičić, T. Matijević, and P. Radunović, "Game-based mobile learning—application development and evaluation," in *Proc. The Sixth International Conference on e-Learning (eLearning-2015)*, 2015.

[42] V. Braun and V. Clarke, "Using thematic analysis in psychology," *Qualitative Research in Psychology*, vol. 3, no. 2, pp. 77–101, 2006.

[43] Y.-C. Chu, "Learning difficulties in genetics and the development of related attitudes in Taiwanese junior high schools," Ph.D. dissertation, Faculty of Education, University of Glasgow, United Kingdom, 2008.

[44] M. V. B. Reddy and P. P. Mint, "Impact of simulation based education on biology student's academic achievement in DNA replication," *J. Educ. Practice*, vol. 8, no. 15, pp. 72–75, 2017. doi: 10.7176/JEP/8-15-04

[45] J. Vijapurkar, A. Kawalkar, and P. Nambiar, "What do cells really look like? An inquiry into students' difficulties in visualising a 3-D biological cell and lessons for pedagogy," *Res. Sci. Educ.*, vol. 44, pp. 307–333, 2014. doi: 10.1007/s11165-013-9379-5

[46] N. Yorek, M. Sahin, and I. Ugulu, "Students' representations of the cell concept from 6 to 11 grades: Persistence of the 'fried-egg model'," *Int. J. Phys. Sci.*, vol. 5, pp. 15–24, 2010.

[47] P. Rajdeep, L. Patel, V. Trivedi, P. Panchal, R. Chaudhari, and K. Parmar, "Learning and evaluating the overlapping roles of physics and physiology in perceiving contrast and resolution in microscopy," *SN Appl. Sci.*, vol. 5, no. 12, pp. 1–10, Dec. 2022. doi: 10.1007/s42452-022-05223-5

[48] G. S. Gould, A. Gilbert, A. J. Pike, and I. J. Menzies, "Interactive touch-screen monitors facilitate collaborative learning of microscopy skills in an introductory-level plant biology lab," *J. Biol. Educ.*, vol. 53, no. 1, pp. 47–53, 2019.

[49] M. Ruščić, A. Vidović, G. Kovačević, and D. Sirovina, "The use of microscopes in school biology teaching," *Resolution Discovery*, vol. 3, no. 1, pp. 13–16, 2018. doi: 10.1556/2051.2018.00054

[50] H. T. Hadji Abas and A. C. Marasigan, "Readiness of science laboratory facilities of the public junior high school in Lanao Del Sur, Philippines," *IOER Int. Multidiscip. Res. J.*, vol. 2, no. 2, pp. 12–20, 2020.

[51] T. Ozkan, C. Tekkaya, and O. Geban, "Facilitating conceptual change in students' understanding of ecological concepts," *J. Sci. Educ. Technol.*, vol. 13, no. 1, pp. 95–105, Mar. 2004. doi: 10.1023/B:JOST.0000019642.15673.a3

[52] E. Fägerstam and J. Blom, "Learning biology and mathematics outdoors: Effects and attitudes in a Swedish high school context," *J. Adventure Educ. Outdoor Learn.*, vol. 12, no. 1, pp. 1–17, 2014. doi: 10.1080/14729679.2011.647432

[53] J. A. Baker, "Studying arthropod species richness in a school-yard natural area: Using inquiry to engage student interest in scientific studies," *The Amer. Biol. Teacher*, vol. 78, no. 7, pp. 575–579, Sep. 2016. doi: 10.1525/abt.2016.78.7.575

[54] A. von Albedyll, A. Fritsch, and D. Dreesmann, "I learned it through the grapevine…": Exploring atypical ecosystems in schools as a new out-of-school learning site," *Amer. Biol. Teach.*, vol. 79, no. 5, pp. 351–364, May 2017. doi: 10.1525/abt.2017.79.5.351.

[55] L. Chavan, "Difficulties in teaching biology concepts by science teachers at upper primary level," *Aayushi Int. Interdiscip. Res. J.*, vol. 3, no. 8, pp. 10–18, Aug. 2016.

[56] P. Lampert, B. Müllner, P. Pany, and M. Kiehn, "Students' conceptions of plant reproduction processes," *J. Biol. Educ.*, vol. 54, no. 4, pp. 400–414, 2020. doi: 10.1080/00219266.2019.1701670

[57] G. Ampatzidis, D. Georgakopoulou, and G. Kapsi, "Clitoris, the unknown: What do postgraduate students of educational sciences know about reproductive physiology and anatomy?" *J. Biol. Educ.*, vol. 55, no. 3, pp. 254–263, 2021. doi: 10.1080/00219266.2019.1679658

[58] A. I. Jabbar and P. Felicia, "Gameplay engagement and learning in game-based learning: A systematic review," *Rev. Educ. Study*, vol. 85, no. 4, pp. 740–779, 2015. doi: 10.3102/0034654315577210

[59] T. Hainey, T. M. Connolly, E. A. Boyle, A. Wilson, and A. Razak, "A systematic literature review of games-based learning empirical evidence in primary education," *Comput. Educ.*, vol. 102, pp. 202–223, 2016. doi: 10.1016/j.compedu.2016.09.001

[60] A. Umamah, "Mobile games-based learning for gamer generations: A systematic review," in *Proc. ICEHUM 2022*, Y. Liu and S. Chujuarjeen, Eds., Paris, France: Atlantis Press, 2023, pp. 125–137. doi: 10.2991/978-2-38476-040-4_13

[61] K.-C. Hou and C.-H. Ho, "A preliminary study on aesthetic of Apps icon design," in *Consilience and Innovation in Design – Proc. Program 5th Int. Congr. Int. Assoc. Societies Design Res. (IASDR)*, Tokyo, Japan, Aug. 2013, pp. 3845–3856.

[62] P. Taquet, L. Romo, O. Cottencin, D. Ortiz, and M. Hautekeete, "Video game addiction: Cognitive, emotional, and behavioral determinants for CBT treatment," *J. Thérapie Comportementale et Cognitive*, vol. 27, no. 3, pp. 118–128, Sep. 2017.

[63] Z. Shen, L. Zhang, R. Li, and R. Liang, "The effects of icon internal characteristics on complex cognition," *Int. J. Ind. Ergon.*, vol. 79, 102990, 2020. doi: 10.1016/j.ergon.2020.102990

[64] A. Marengo, A. Pagano, and L. Ladisa, "Mobile gaming experience and co-design for kids: Learn German with Mr. Hut," in *Proc. European Conf. e-Learning (ECEL)*, Prague, Czech Republic, Oct. 27–28, 2016.

[65] S. B. Zaibon, "User testing on game usability, mobility, playability, and learning content of mobile game-based learning," *Jurnal Teknologi (Sciences & Engineering)*, vol. 77, no. 29, Dec. 2015. doi: 10.11113/jt.v77.6848

[66] L. Mivehchi and L. Rajabion, "A framework for evaluating the impact of mobile games, technological innovation and collaborative learning on students' motivation," *Human Syst. Manag.*, vol. 39, no. 1, pp. 133–142, 2020.

[67] J. L. Plass, B. D. Homer, and C. K. Kinzer, "Foundations of game-based learning," *Educ. Psychol.*, vol. 50, no. 4, pp. 258–283, Oct. 2015. doi: 10.1080/00461520.2015.1122533

[68] F. D. Davis, "Perceived usefulness, perceived ease of use, and user acceptance of information technology," *MIS Quart.*, vol. 13, no. 3, pp. 319–340, Sep. 1989. doi: 10.2307/249008

[69] A. Krouska, C. Troussas, and C. Sgouropoulou, "Mobile game-based learning as a solution in COVID-19 era: Modeling the pedagogical affordance and student interactions," *Educ. Inf. Technol.*, vol. 27, 2021. doi: 10.1007/s10639-021-10672-3

[70] J. Huizenga, W. Admiraal, G. Dam, and J. Voogt, "Mobile game-based learning in secondary education: Students' immersion, game activities, team performance, and learning outcomes," *Comput. Human Behav.*, vol. 99, pp. 137–143, 2019. doi: 10.1016/j.chb.2019.05.020

[71] J. Hamari, D. J. Shernoff, E. Rowe, B. Coller, J. Asbell-Clarke, and T. Edwards, "Challenging games help students learn: An empirical study

on engagement, flow, and immersion in game-based learning," *Comput. Human Behav.*, vol. 54, pp. 170–179, 2016. doi: 10.1016/j.chb.2015.07.045

[72] I. Granic, A. Lobel, and R. C. M. E. Engels, "The benefits of playing video games," *Amer. Psychol.*, vol. 69, no. 1, pp. 66–78, 2014. doi: 10.1037/a0034857

[73] P. Rooney, "A theoretical framework for serious game design: Exploring pedagogy, play and fidelity and their implications for the design process," *Int. J. Game-Based Learn.*, vol. 2, no. 4, pp. 41–60, 2012. doi: 10.4018/ijgbl.2012100103

[74] R. G. Sagge and R. T. Segura, "Designing and developing video lessons in mathematics using code-switching: A design-based research," *International Journal of Information and Education Technology*, vol. 13, no. 9, pp. 1391–1398, 2023. doi: 10.18178/ijiet.2023.13.9.1942

[75] R. G. Sagge, "Beyond static textbook illustrations: Development of Augmented Reality-based Materials (ARM) for geometry," *Int. J. Inf. Educ. Technol.*, vol. 15, no. 8, pp. 1687–1697, 2025.

[76] S. P. Bacio, "Identifying learners' least-mastered competencies in Filipino 11: A foundation for digital module development," *International Journal of Information and Education Technology*, vol. 15, no. 6, pp. 1277–1288, 2025. doi: 10.18178/ijiet.2025.15.6.2330

[77] R. G. Sagge Jr. and S. P. Bacio Jr., "Video explainer, e-module, or both: which is better to improve statistics performance of graduate students?" *International Journal of Evaluation and Research in Education*, vol. 13, no. 5, pp. 3194–3201, 2024.

[78] S. M. C. Quero and S. P. Bacio Jr., "Podcasts developed through the Successive Approximation Model 1 (SAM 1): A tool for teaching research to broadcasting students," *International Journal of Information and Education Technology*, vol. 15, no. 3, pp. 525–538, 2025. doi: 10.18178/ijiet.2025.15.3.2263

[79] P. M. Torion and S. P. Bacio, "Video lessons for the course Introduction to Computing through Online/Offline Mode (ICOM): Its development and evaluation," *International Journal of Information and Education Technology*, vol. 14, no. 6, pp. 845–855, 2024. doi: 10.18178/ijiet.2024.14.6.2110